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An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention

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The Intermittence of Minimal Visual Sensations

THESIS

Presented to the University Faculty of Cornell University for the Degree of Doctor of Philosophy

BY

C. E. FERREE

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AN EXPERIMENTAL EXAMINATION OF THE PHENOMENA USUALLY ATTRIBUTED TO FLUCTUATION OF ATTENTION.[1]

By C. E. FERREE, A. M., M. S.

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[1]From the Psychological Laboratory of Cornell University.

INTRODUCTION.

It is commonly admitted by experimental psychologists that no final explanation has as yet been offered of those fluctuations of minimal stimuli and minimal stimulus-differences which go by the general name of 'fluctuations of attention.' We have peripheral theories and central theories and mixed, peripheral-central theories; and, without doubt, we have a good deal of scattered knowledge about the conditions which underlie the phenomena in certain of the fields of sense. But this chapter of psychology is, on the whole, still open. G. E. Müller, for instance, writes in 1904 that "zu feststehenden Resultaten von allgemeiner Bedeutung haben indessen diese Untersuchungen, die sich in ihren Ergebnissen und Schlussfolgerungen vielfach wiedersprechen, bisher noch nicht geführt." [1] Unless one is prejudiced in favor of some particular theory, one cannot but subscribe to this opinion.

Considerations of this sort led us to begin a systematic investigation of the subject which has extended from the winter of 1903 to the present time. Cutaneous and visual stimuli were used; but, since the former gave uniformly negative results, it has been possible to confine our attention almost exclusively to the latter. We had hoped, likewise, to include auditory stimuli in this series of investigations, but circumstances have rendered it necessary that we make them the subject of future study.

It has become evident in the course of the work that a complete account of the fluctuation of visual stimuli must take into consideration also the fluctuation of the negative after-image. The results of this investigation will be made the subject of a second article, to be followed by a third in which the conclusions of the two preceding articles will be considered from the standpoint of theory and in the light of preceding work. The present study is a reproduction, with some changes, of a paper read before a meeting of experimental psychologists held at Cornell University in March, 1904. It has seemed advisable to publish it in its present form, rather than to wait for a more complete treatment, as was originally planned, because of the evident revival of interest in the problem and the appearance of the recent papers of Dunlap,[2] Killen,[3] and Hammer.[4]

For the sake of clearness, the following order of presentation will be adhered to as closely as possible:

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[1] Die Gesichtspunkte und die Tatsachen der psychophysischen Methodik, 1904, 110.

[2] K. Dunlap: Psychol. Rev., XI, 308.

[3] B. Killen: this *Journal*, XV, 512.

[4] B. Hammer: Zeits. f. Psych., XXXVII, 363; *cf.* C. E. Seashore, *ibid.*, XXXIX, 668.

1st. A statement of theory sufficiently comprehensive to render the results intelligible in terms of it.

2nd. A statement of the lines of investigation.

3d. A statement of results in general.

4th. A statement of results in detail.

I. Visual Stimuli.

(i) *Statement of Theory.* It is our purpose to show in this paper that the intermittences of sensation resulting from minimal visual stimuli which have been referred for explantion to fluctuation of attention are, in reality, simply adaptation phenomena somewhat obscured by the special conditions.

Adaptation is, in itself, a continuous phenomenon, but its continuity is interfered with by eye-movement,[1] blinking, etc. Through these influences, probably essentially through that of eye-movement alone, it becomes an intermittent process, whether the stimulus be liminal or intensive, provided that proper areas be used. The conditions are especially favorable for short periods of intermittence when the stimuli are liminal and of small area.

Eye-movement tends to delay adaptation when the stimulus is liminal and of small area. When the stimulus is much above the limen and the area very small, complete adaptation is prevented, because, under these conditions, no one part of the retina is stimulated long enough to produce the required physiological effect. Also, under such conditions, it is of very short duration, when attained, because a slight shift of the retina is sufficient to produce a complete change in the area stimulated and thus to afford the adapted elements the relief necessary to the revival of sensation. When, on the contrary, the area is very large, these relatively small eye-movements do very little towards relieving the part of the retina stimulated; consequently, complete adaptation takes place much more quickly, and persists apparently indefinitely, unless relief be similarly afforded by some other agency. Areas ranging from 2 mm. to 3-4 cm., viewed at a distance of 1 meter or more, are especially favorable for short periods of intermittence; hence, in the previous investigation of this phenomenon, it is only natural that they should have been chosen and the remainder overlooked.

In all experimental work, however, the conditions that are unfavorable to the production of the phenomenon are as im-

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[1] While working with after-images, this past year, we chanced upon another factor in adaptation, which (so far as we can at present tell) promises to be important. Just how much it bears upon the fluctuation of minimal visual stimuli cannot now be stated. We hope, however, to discuss it fully in the article on the fluctuation of after-images.

portant as, and often more important, for theory, than those more favorable. This proves to be true in the case of what are commonly called 'fluctuations of attention.'

Our plan of experimentation, in general, has been to isolate, and test out separately, the probable factors involved, central and peripheral, endeavoring so to vary the conditions as to relieve introspection of any undue burden of analysis. Where the possible factors are numerous and complex, introspective analysis unaided can scarcely be relied upon to solve the problem.

(ii) *Lines of proof.* It is proposed to show:

(1) That involuntary changes in accommodation are not essential factors in the phenomenon. (2) That a stimulus which is not, in itself, intermittent, acting upon the optic centre, does not produce an intermittent sensation. (3) That all liminal stimuli do not fluctuate. (4) That adaptation is an intermittent process under the conditions holding for fluctuation. (5) That adaptation and fluctuation are identical. (6) That adaptation is intermittent chiefly because of eye-movement. (7) That the same correspondence between adaptation and fluctuation obtains in indirect vision.

(iii) *Results: General.* We have the following results to offer at this stage of the work.

A. Involuntary changes of accommodation are not essential.

Aphakial subjects experience these fluctuations with apparently no greater variation of phase than can be accounted for on the ground of normal individual differences. Hence, we can conclude that involuntary changes of accommodation play no essential part in the phenomenon.

B. A non-intermittent stimulus produces a continuous sensation.

A minimal and continuous light sensation, produced by electrical stimulation of the cerebro-retinal mechanism, does not fluctuate. Here is a liminal stimulus capable of affecting the optic centre, and pouring in upon it, the effect of which gradually dies out, but shows no signs of intermittence. This fact would seem to indicate that we must look to the periphery for an explanation of fluctuation; for if it were conditioned by central factors, it would be difficult to see why an exception should be made in this case, which is distinctive only in that certain of the peripheral factors which usually modify retinal stimulation are omitted.

C. Not all liminal stimuli fluctuate.

Liminal visual stimuli of large area, also certain combinations

of stimulus and background with very small areas, do not fluctuate.

D. Adaptation is an intermittent process under the conditions holding for fluctuation.

Adaptation, in general, with areas equal to those with which fluctuations are obtained, is a periodic phenomenon, no matter what the intensity of the stimulus used. The condition of a just perceptible difference between the stimulus and background is favorable, but is by no means essential to the phenomenon. Any stimulus that will completely adapt into its background will do so intermittently within this range of areas; while a stimulus whose qualitative relation to its background is such that it will not disappear completely shows periodic increase and decrease in intensity.

E. Adaptation and fluctuation are identical.

Whatever conditions relative to the stimulus, or to the combination of stimulus and background, affect the adaptation time, produce a similar effect on the fluctuation time; the effect showing itself either in the phase of visibility, or in the phases of both visibility and invisibility.

Some of the ways by which this correspondence was shown are:

(a) *Fading of the stimulus into its proper gray during the course of a single fluctuation.* In the course of a single fluctuation a colored stimulus is observed to fade into a gray, of a shade depending upon the color used, as always happens in complete color adaptation. Further, the times required for the several colors to fade sustain a very definite relation to their adaptation times. In order of their value from least to greatest, they are (for our stimuli) red, green, blue and yellow. There is little difference, however, in the times required for the disappearance of the residual grays in each case. Moreover, such differences as do occur are chance variations, as is shown by the following averages: red, 1.65 sec.; green, 1.97 sec.; blue, 1.61 sec.; yellow, 1.65 sec. Thus it would seem that the difference in the phases of visibility for these four colors, which is the phenomenon discussed in the next section, does not depend upon their respective brightnesses, but is a duration peculiarity of the processes themselves.[1]

[1] This point is of two-fold importance. (1) It suggests that the adaptation time of a color is not a function of its brightness; *i. e.*, yellow and red have in no wise different adaptation times because of their positions in the white-black series. (2) It shows that the different visibilities in the fluctuation experiments are not conditioned by the relation of the brightnesses or proper grays of the colors used to the background, but are true expressions of characteristic differences in the color processes themselves.

(b) *Comparison of fluctuation times with adaptation times for colors and grays.* Colors and grays were found to have an order of fluctuation times corresponding to their adaptation times. Four colors, red, green, blue and yellow, gave very different fluctuation periods as compared with each other and with no. 27 Hering gray. The visibility times obtained were in the following order: red, green, blue and yellow, the yellow being nearly four times as long as the red. The complete adaptation times for sheets of the same colors were found to have the same order of length and a rough correspondence as to ratio of length. Further, a striking fact came out with regard to the phases of invisibility. Since red, for example, has a shorter phase of visibility than green, one might naturally expect that its phase of invisibility would also be shorter than the invisibility time of green. The reverse, however, is true. Red has a longer invisibility than green, and this peculiarity is especially marked if one considers the proportionality between the phases, *i. e.*, the ratio invisibility: visibility. The same thing is true of the complementaries blue and yellow. Clearly, we cannot look for a central explanation of this peculiarity; but it seems just what we might expect of adaptation from the standpoint of the compensation theory. The recovery process for the red is the green process. The green process is longer and seemingly more tenacious than the red, as is shown by the adaptation experiments proper, and is further borne out by the longer duration of the green after-image. A similar relation obtains in the blue-yellow process. We have now in progress a series of experiments that will enable us to make an exact comparison of the recovery times for these four colors.

(c) *Combinations of stimulus and background that influence adaptation times correspondingly influence fluctuation times.* By keeping the background constant and varying the stimulus, or conversely, by keeping the stimulus constant and varying the background, a difference in the period of fluctuation was obtained, showing itself chiefly in the phase of visibility. This same thing held in the recognized adaptation experiments. The variations of the phases of visibility and invisibility that were produced in the adaptation experiments were produced also in the fluctuation experiments, the only departure from precise correspondence being that the differences were more marked in the former case, as would be expected from the longer duration of the process.

(d) *Method of areas.* By adequate variation of the area of the stimulus, the phase of visibility was varied from quite long with small areas to nearly zero with large, while the phase of invisibility ranged from very short with small areas, to approximate infinity with large areas, *i. e.*, the faded-out stimu-

lus did not reappear. Thus the phases of visibility and invisibility are, inversely to each other, functions of the stimulus area. The curve representing the phase of visibility starts high on the ordinate and drops down fairly regularly to near the abscissa; while the curve representing the phase of invisibility starts near the abscissa and rises to infinity. The areas chosen do not make the phase of visibility infinite with liminal stimuli; but it is presumable that an area small enough to do this might be found. The curve representing the total period begins high on the ordinate, bends down towards the abscissa, rises again, and passes to infinity. A similar effect, much more marked, was obtained in the adaptation experiments. With the smallest areas used above, the spot never disappeared. Thus the curve representing the whole period starts at infinity, bends down, but not so near to the abscissa as before, rises again, and passes back, but much more irregularly, to infinity. Further, if we took areas sufficiently large, not only did the faded-out stimulus not become visible again under the conditions of fixation observed in such experiments, but it refused to reappear with quite extensive voluntary eye-movements.

Now there seems no way of explaining these results from any peculiarity of function in the centre. In the case of liminal stimuli, the intensities were chosen subjectively equal, consequently there could be no reason for a central discrimination, on the ground of intensity, adequate to account for the wide range of variation obtained; and as for the adaptation experiments, a very flood of vaso-motor waves,[1] etc., would scarcely suffice to wipe out stimuli of so great intensity. If it be argued that it is not fair to attempt to carry over this explanation to the adaptation experiments, we must reply that there would remain, then, the very great difficulty of explaining the close correspondence in the results obtained in the two series of experiments, if entirely different causes were ascribed to the two sets of phenomena. In favor of physiological rhythm, it might be said, however, that there seems a bare possibility of establishing a connection between it and eye-movement. But only in this way could it fit into a theory that should explain all the results cited above. Again, if from any standpoint it be argued that central factors[2] are involved in eye-movement, blinking, etc., and that these influences, therefore, make for a central theory, we reply that the movements are more likely to be reflex, made in sympathy with the changes and needs of the retina. But granted that they are central, they still play no greater part in the explanation of the phenomenon than is

[1] J. W. Slaughter: this *Journal*, XII, 313.
[2] E. A. Pace: Philos. Studien, VIII, 388; XX, 232.

the case with adaptation in general. The part played by all of these factors becomes a common problem, to be investigated in connection with adaptation, and not substituted for it as a *vera causa*. There seems, likewise, little chance of explanation of these results from the side of attention. In fact, they seem to be precisely contradictory of any theory that seeks its account from this source. Increase in area of the stimulus is presumed to be equivalent to an increase in intensity, as regards its noticeability or its efficiency[1] for attention. Efficiency, or whatever may be considered as its equivalent in these results, let the criterion be what it will, is reduced to a minimum.

F. Adaptation is rendered intermittent chiefly by eye-movement.

That eye-movement[2] is chiefly responsible for the intermittence of adaptation seems evident from the results. Blinking might enter in, as an occasional factor, to delay adaptation or cause the reappearance of the faded-out stimulus; but it is much too infrequent to explain all of the reappearances. Besides, it could offer no explanation for the difference in the times of visibility and invisibility for the different areas, since

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[1] There are, probably, two factors which give an increased area an increased efficiency for attention. (1) There is an actual increase in the intensity of the sensation. For example, when our stimulus was obtained by light transmitted through opal glass, the source of light had to be moved farther away in order to give a liminal effect when the area of the stimulus diaphragm was increased. Likewise, when the stimulus was seen by reflected light, the opal glass plate had to be moved farther out from the background when the area of the stimulus was increased. (2) The increased area occupies more of the field of vision; hence the rival area is not only of less extent (fewer distracting factors, etc.), but is pushed more and more into the field of indirect vision. The first factor was ruled out by decreasing the intensity of the stimulus until it was liminal. The second, however, operated to give our large areas greater efficiency for attention. But in spite of this, the large areas, although favoring rapid adaptation, gave us minimal visibility. Besides helping to make our point for adaptation, this result serves as a striking illustration of how little the central factors avail against the peripheral in so-called sensory attention.

[2] The other factor conditioning adaptation is probably, likewise, essentially dependent upon eye-movement. At least, the modification which gives it a bearing upon this problem is caused by eye-movement. The effect produced is, similarly, a freshening of the adapted elements, and will be understood, throughout the discussion, to supplement the change produced by shifting the adapted elements into a region of different stimulation. Since its action in point of time follows immediately upon eye-movement, and does not change, but only supplements, the restoration produced by change of stimulation, there was little apparent need of it to explain the results of the following tables. Hence, had it not come to light in the work on after-images, it probably would have been entirely overlooked.

the amount of relief afforded in each case would be the same. Eye-movement alone seems adequate to do this.

That eye-movement produces its effect in the manner we have stated probably needs further proof. Hess[1] has contended that a spot once adapted-out will not reappear so long as fixation is held perfectly steady; but his experiments do not indicate how eye-movement causes reappearance. MacDougall[2] explains the effect of eye-movement upon the reappearance of minimal visual stimuli on the basis of innervation. Innervation, however, could not account for phases of invisibility ranging from nearly zero to infinity; besides which, extensive voluntary eye-movements were wholly ineffective to revive sensation in the case of the largest areas used. Similarly, the mechanical effects of pressure, etc., are ruled out. Hence we seem not only warranted, but forced, to fall back for explanation upon an actual shift of the adapted elements away from the area of stimulation.

A more direct experimental confirmation, than was afforded by the method of variation of areas, of the view that eye-movement interferes with the course of adaptation, and is also the conditioning factor for the wide range of variability found in the phases of visibility and invisibility in the fluctuation experiments, is given by the following results. An examination of the average frequency of eye-movement in the horizontal and vertical planes during fixation showed that three of our observers had a marked excess in both frequency and range in the horizontal, while the fourth had an excess of frequency in the vertical, but of range in the horizontal plane. This appeared to mean that, for three observers, there was a greater change of stimulation, and consequently greater relief for the adapted elements, in the horizontal than in the vertical direction, while the reverse was true, though probably to a less degree, for the fourth. To test this interpretation, stimuli longer than broad were used,[3] *e. g.*, slips of paper 5 mm. x 40 mm. When these were placed with the longer dimension vertical, the shorter dimension would fall in the direction of greater unsteadiness of fixation for the three observers who had the excess of eye-movement in the horizontal plane. Consequently, a maximal interference with adaptation for these stimuli would be obtained, and one might expect an increase in the phase of visibility and a decrease in the phase of invisibility. On the other hand, if the longer dimension were placed in the horizontal and the shorter in the vertical plane, a mini-

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[1] C. Hess: *von Graefe's Archiv*, XL, 2, 274.
[2] W. MacDougall: *Mind*, XI, 316; XII, 289.
[3] This procedure was suggested by Professor L. Witmer, of the University of Pennsylvania.

mal interference possible to these stimuli would be secured, and a decrease in the phase of visibility and an increase in that of invisibility should ensue. For the fourth observer, with the stimulus arranged as described above, the reverse should be true; but probably not in so marked a degree, since his range was greater in the horizontal, and this fact to a certain extent counteracted the effect of frequency. This observer also had an astigmatism in the vertical plane, which caused the stimulus to become spreading and diffuse in the horizontal, a result equivalent to greater breadth for adaptation.

That these methods of arrangement of stimulus caused a marked change in the phases of visibility and invisibility for each observer will be seen by inspection of the Tables. Indeed, the correspondence between the quantities: $\frac{\text{visibility} \div \text{invisibility}}{\text{visibility}^1 \div \text{invisibility}^1}$ and $\frac{\text{frequency}}{\text{frequency}^1}$ is much closer than was anticipated.

G. Correspondence of adaptation with fluctuation in indirect vision.

To show that fluctuation in indirect vision is not a special phenomenon, but that the correspondence between adaptation and fluctuation obtains here as well as in direct vision, the following set of experiments was carried out. (1). Beginning with direct vision, a liminal stimulus was moved successively 4, 8, 12, 16, etc., cm. towards the periphery, and records were obtained at each point. A parallel set of records was obtained with the same stimulus at full intensity. Both sets of records showed a fairly regular decrease of visibility and increase of invisibility as the stimulus was moved towards the periphery. The adaptation times obtained in a separate series of experiments with the same stimulus also showed a corresponding decrease from direct vision to periphery.

(2). An increase of area with liminal stimuli in indirect vision gave a decrease of visibility and an increase of invisibility, very much the same as was obtained for direct vision.

There seems little doubt that all the results secured for direct vision could have been paralleled for indirect vision. The above series, however, satisfied us that the phenomenon here is essentially the same. It seems, then, that the conclusion is justified that adaptation causes the disappearance of the stimulus, and unsteadiness of fixation the wide range of visibility and invisibility in case of different areas, and the restoration when complete adaptation has set in; and that this effect is due to relief of adapted elements by actual shift away from the area of stimulation, or rather into a region of different stimulation.[1]

[1] Together with the supplementary factor mentioned but not specified above,—if this prove to have the efficacy which we now incline to ascribe to it.

H. Facts of minor importance.

The following facts of minor importance may also be cited.

(a) *Result of increasing the distance of the observer.* The effect of increasing the distance of the observer from the stimulus was tried The area subtended by the stimulus on the retina follows the law of inverse squares. Although the phase of visibility increased and the phase of invisibility decreased with the increase of the observer's distance, still the results did not at all closely follow those obtained by the corresponding variations of area observed at a distance of 1 meter. The phase of invisibility increased much more rapidly with the increase of distance than was demanded by the law of inverse squares. This seems to argue in favor of eye-movement; for the greater the observing distance, the greater is the shift of the adapted elements away from the stimulating area with each eye-movement; hence the greater is the interference with the course of adaptation.

(b) *Connection between reappearance, and conscious eye-movement and blinking.* Experiments for recording[1] the connection between reappearance and conscious eye-movement and blinking showed coincidence in from one-third to one-half the total number of cases.

(c) *Effect of moving the eyes voluntarily.* Records of series in which an observer purposely moved his eyes at short intervals showed very few fluctuations. Another observer was directed to relieve the strain when, and as, impulse directed. No fluctuations were experienced in one revolution of the drum: 102 secs.

(d) *Effect of momentary cessation of the stimulus.* Anything else that temporarily relieved the retina, such as the interposition of some object between the source of light and the screen when the spot was made visible by transmitted light, caused reappearance when the spot had vanished, and delayed disappearance when the spot was visible.

(e) *Influence of practice.* An inexperienced observer usually obtained longer times of visibility and shorter times of invisibility until a certain stage of practice was reached. Some, indeed, were unable at first to get fluctuations at all. This is precisely what would be expected as the result of unpractised fixation upon adaptation. Further, the result seems incompatible with the theory of fluctuation of attention, for one

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[1] The method of recording was simple. When reappearance came with conscious eye-movement or blinking, *O* substituted for the usual release of the key an extra pressure and immediate release. With practice, this method offered little if any distraction.

would expect practice to increase, certainly not to diminish, efficiency of attention.

Again: towards the close of a sitting, with one of our observers, the phase of visibility began to lengthen and the phase of invisibility to decrease very perceptibly: in a few cases so much so, that disappearance did not come at all. At these times the observer complained of eye-fatigue and inability to fixate steadily. This result, too, testifies for adaptation and against central factors.

(f) *Introspective evidence.* Introspection also furnishes valuable evidence. For all observers the spot faded gradually,[1] and as this process went on the strain of attention increased, reaching its maximum with the disappearance of the stimulus, and continuing until reappearance, when momentary relief was experienced. The natural attitude of our observers seems to have been to hold the sensation as long as possible. Hence it was to be expected that the strain should increase with the decrease of the sensation. Had their attitude been different, had they, for instance, been instructed that disappearance was the thing to be expected and attained, it is possible that relief might have come with invisibility: that relaxation of attention might then have ensued. Even so, it would have been the result and not the cause of the disappearance. Moreover, the conditions of the experiment make for stimulation rather than for fatigue of attention. The constantly changing stimulus, the unexpected reappearances, etc., are attention-compelling to a high degree. There is no monotony. There are rather ele-

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[1] The conflicting reports on this point in the literature have probably been due to the peculiar difficulties attending observation with the Masson disk. With stationary stimulus and background, such as were used by us, there is no doubt that the stimulus disappears gradually. If, on occasion, the actual change in intensity could not be detected, the disappearance was gradual and progressive in point of area, the background encroaching upon the stimulus from one direction or another. More will be said about this type of disappearance in a later article.

If it be contended that stimuli whose intensity can be detected in decrease are not liminal, we reply that, in practice, just noticeability is not so consistently obtained that the detection is impossible. We have worked most carefully to get this degree of intensity, approaching the point from either direction, and still the observer would report, during the course of the fluctuation, that the stimulus faded out. What holds of our stimuli has probably held also of others; for we undoubtedly succeeded in getting finer adjustments of intensity with the arrangement finally adopted than was possible with the Masson disk. With the Masson disk itself fading was recorded by our observers.

Dealing, as we did, with many degrees of intensity, facility for judging intensity changes was naturally acquired. During this time, besides, two of our observers were regularly working on the determination of visual limens.

ments of fascination. As one observer stated, "one is always on the alert to see what will happen next." In fact, were we endeavoring to demonstrate an unwavering attention, scarcely a better set of conditions could have been selected.

It will be understood here, as elsewhere in the discussion, that our contention is not that attention does not fluctuate.[1] That is a question aside. We are merely concerned with showing that certain phenomena, that have usually been attributed to fluctuation of attention and cited as its classical demonstration, are to be otherwise explained. That there is fluctuation on the content side of consciousness goes without saying: the sensation comes and goes. But we believe not only that this fluctuation is to be explained wholly by reference to the sense process, but also that the associative factors that aid in the exaltation of the sensation are all the more active because of this sinking of the content below the limen on the peripheral side. We may add then that, in so far as the facilitation of the process elevated to prominence, or the inhibition of other processes, depends upon associative factors, it should be maintained that the conditions of these experiments make for an exalted and sustained attention.

(iiii). *General description of method and apparatus.* Before going more into detail as to method and results, we may remark that all devices that did not produce decided changes of result have been considered as worthless for yielding evidence in a case where without change in the experimental conditions the variations are so considerable. One finds cited in the literature, as due to some change in method or in support of some particular theory, variations no greater than our records showed from day to day without any change in the experimental conditions. There is, in dealing with this problem, especial need for clearly cut and decisive methods of experimentation, as well as for extreme caution in referring slight changes in result to a variation of experimental conditions.

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[1] In so far as attention is considered as a state or mode of consciousness, it may be said to fluctuate. But interpreted in this sense, it is ruled out for purposes of explanation. We must look, instead, to the processes concerned in giving this particular state or mode to consciousness. The above paragraph is written from the point of view of the central processes involved. If we are to investigate the action of these processes, it would be well to have consciousness as purely central as possible, *i. e.*, ideas should be worked with, instead of sense perceptions. The changing content given by the peripheral process is fatal to the determination whether the central processes will act continuously for any length of time in a given relation.

In general, we probably recognize too little the difference between attention where the content is peripheral, and attention where it is central. The distinction should undoubtedly be made in any discussion of fluctuation.

We have even found it necessary not to be obliged to compare results obtained at different sittings, because of the subjective changes that occurred from time to time in spite of experimental control. Our comparisons have, therefore, been planned in series to be finished at a single sitting, and the order of their presentation has been changed so as to compensate as much as possible for probable changes in the condition of the eyes and fixation-apparatus from the beginning to the close of the period. Series, then, were compared from day to day, rather than the members needed to make a single series.

For registration, throughout all of the work, a Ludwig-Baltzar kymograph was used; together with a Marey tambour and bulb, whereby the entire course of the fluctuation as well as mere appearance and disappearance could be traced, when desired; and an electromagnetic time-marker in circuit with a metronome, enclosed in a soundless box. All of this apparatus was screened from the observer by a sliding curtain. The work was done mostly in a long room, the 'reaction room,' with the windows all at one end. Thus cross-lights, unequal illumination of the background, etc., could be avoided. The observer sat with his back to a high window and his head in a head-rest fastened to the edge of a long table, along which the frame bearing the stimulation apparatus was moved as required. The time unit throughout is 1 sec.

(v) *Results.* (*In detail.*) It is scarcely necessary to mention that the results, unless otherwise stated in the tables, are averages obtained from a large number of records. In the main, throughout the work, they were confirmed not only by the writer and the observers cited: *viz.*, Misses Fitch (*F*) and George (*Ge*) and Messrs. Sabine (*S*) and Galloway (*Ga*), but also by a number of the students of the junior training course, either as a part of their regular work, or as substituted for it. Where results have not been obtained from all of the regular observers, this has been due solely to lack of time. *S* and *Ge* gave the least and *Ga* the longest time to the work. All four observers were students in the department of psychology, and had had laboratory training. *Ga* had also had experience with the problem, both as experimenter and observer, at the University of Michigan.

A. Involuntary changes of accommodation are not essential.

Two aphakial subjects were experimented upon. One of them had so little accommodation that words in fine print could not be moved more than 2 mm. farther from or nearer to his point of clearest vision (determined by the focus of his glasses) without becoming less distinct. His head was clamped in a

head-rest, and the card slid along a meter rod at the level of his eyes in the median plane. Every precaution was taken to secure accuracy. It may safely be said that the man was practically without accommodation. As was stated before, the results obtained from both of these men were uniformly negative, *i. e.*, no greater variations were found than can be explained on the ground of normal individual differences.

B. A NON-INTERMITTENT STIMULUS PRODUCES A CONTINUOUS SENSATION.

The well-known fact that make or break of a direct current produces a flash of light, if the electrodes are properly applied, led us to believe that, if the current were rapidly interrupted, these flashes might be caused to fuse into a continuous sensation. This proved to be true. An interrupter so constructed that six makes and breaks occurred with every revolution of the interrupting cylinder was used. It was driven by a motor, and its speed of revolution was regulated by a transformer,[1] so finely graduated that a change of a single interruption could be obtained. In circuit with the observer and the battery was inserted a resistance rack of German silver wire, also a Westinghouse ammeter graduated in milliamperes. By this arrangement it was possible to keep the current flowing through the circuit absolutely constant. A speed indicator was also used. This was rendered necessary for the double reason that the quality of the stimulus depended upon the rate of interruption, and that any change in the rate influenced the amount of current flowing through the circuit. This latter phenomenon was probably due to induction effects in the coils of wire used. The number of Leclanché cells required to produce the stimulation was usually eight, although as few as four and as many as twelve were used for different observers. The current flowing through the circuit, when liminal effects were obtained, ranged from one to two milliamperes. The one electrode was placed in the hand and the other, a sponge electrode, above the eye on the nasal side. The observer was stationed in the

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[1] The speed-transformer, made to our order, was in the form of a segment of a cone, with a grooved surface for the retention of the motor and interrupter belts. The dimensions of the segment were such that the decrease in circumference from groove to groove was very small. This arrangement, together with graduated pulleys on the motor and interrupter, made very slight changes of speed possible.

The interrupter consisted of two brass cylinders with six equal open and closed spaces on either surface. An insulating cross-section separated the two cylinders. This duplicate arrangement was not necessary, except that it made the connections more convenient for our purpose, and that, by a proper setting of the brushes, the instrument could also be used as an alternator. The motor and interrupter were mounted on sliding frames, in order that the belts might be kept taut.

dark-room, and allowed to adapt. Then the current was applied, and carefully worked down until liminal effects were produced. The sensation chosen for observation was of the nature of an irregular patch or cloud of light, varying in color for different observers through violet, blue, and yellow.

The sensation, when liminal, usually lasted about 30 seconds, gradually fading out, and in no case reappearing however long the current was applied. The effects obtained at different rates of interruption show differences. Lower rates usually produced a series of flashes, in which more or less irregular patterns were made out. A little higher rate produced bars on a colored background. With a still higher rate, the bars assumed a radial position around a dark opening fringed with colored light. Here began the transition stage. An increase now gradually changed the effect to an uniformly colored field. This fusion usually came at rates ranging from 85-100 interruptions per second. One observer at 80 saw a dark violet field; at 85, purple; at 100, blue; and from 120-162, yellow. It would be interesting to discover whether there is a definite order in the succession of colors for all observers as the rate is increased. The point being merely incidental to our purpose, the investigation was not carried far enough to determine this.

That the retina is stimulated is indicated by the following experiment. A rate of interruption was chosen that would produce bars. The observer stimulated each eye separately and noted the patterns obtained. Then the electrodes were applied above both eyes simultaneously. It so happened that the bars for one eye were inclined towards the horizontal, and for the other towards the vertical. When both eyes were stimulated at once, and the fields superposed, the two patterns still remained distinct, with the bars set obliquely to each other. As to whether the visual substance was involved, the experiment showed that there was always an after-effect, which behaved much as after-images do. However, there was rarely any trace of complementary coloring. In any event, the result goes to prove that a continuous stimulation, reaching the optic centre, does not produce an intermittent sensation.

The data of C. and D. are, for convenience, subsumed under E., to aid in showing the correspondence between adaptation and fluctuation.

C, D, E. Adaptation and fluctuation are identical. Correspondence is shown by:

(a) *Fading of the stimulus into its proper gray during the course of a single fluctuation.* A Masson disk of the standard dimensions was used. The colors (Hering standard) were

red, green, blue, and yellow. The background was neutral engine-gray, darkened by 180° of velvet black.

The change into a gray differing from the background was first reported by Dr. Bentley. Better to bring out the phenomenon, a comparison ring of gray was made concentric with the colored ring. The judgment was difficult, and it has not been possible as yet to repeat the experiment under more favorable conditions. The grays into which the colors changed were judged of different brightnesses in the order, from least to greatest, of blue, red, green, and yellow. These grays correspond to those obtained when these particular colors, saturated, were adapted down.

Adaptation, then, evidently carries the colors to the limen. That it is also adequate to get rid of the gray remaining cannot be questioned. Consequently, it does not seem necessary to supply another process to complete the disappearance, especially when there is nothing in the course of the phenomenon to indicate the need of such a supplement. Introspection shows the change from start to finish to be uniform and contin-

TABLE I.[1]

Ga. Fading of a color into its proper gray during the course of a single fluctuation.

Stimulus	Number of Fluctuations	Changes to Gray	Vis. Color	Vis. Gray	Invis.	Order of Brightness of Gray
Red, 2x5 mm.	21	8	2.4	1.65	1.99	3d.
Green, " "	14	7	2.99	1.97	1.79	2d.
Blue, " "	13	7	3.57	1.61	2.04	4th.
Yell'w, " "	14	6	3.70	1.65	2.02	1st.

uous. It will be noticed that the difference between the total phase of visibility for the four colors in Table I is not nearly so great as it is in Tables II, III, IV, and V. The recovery-peculiarities characteristic of adaptation are also much less noticeable in the phases of invisibility. This difference in result is always found when the data for the Masson disk and the stationary system are compared.

(b) *Comparison of adaptation time and fluctuation time for colors and grays.* (1) *Fluctuation.* Squares of paper were

[1]The writer must apologize to the reader for the ragged appearance of this and the following Tables, owing to the various number of decimal places to which the calculations have been carried out; and must also deprecate any claim to especial accuracy in the case of the longer decimals. He had intended to round-off the figures to two places, but this was inadvertently omitted. Rather than delay the printers, he has allowed the Tables to stand as they were in MS.

pasted upon gray card-board and placed behind an opal glass plate. They were thus seen by reflected light through the opal glass. The intensity was easily regulated by slight changes in the distance of the plate from the card-board. Different makes of standard colors were used at different times. The stimuli for the following Tables were cut from Milton-Bradley papers. The size of the squares was, in each case, 2 cm. x 2 cm., and the distance of the observer 1 meter. All other conditions were the same throughout.

TABLE II.

Ga. Comparison of fluctuation time with adaptation time using colors and grays. Fluctuation: showing that visibility and invisibility have characteristic adaptation and recovery peculiarities.

Stimulus	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Invis.: Vis.	Period
Gray, 2x2 cm.	4.34	1.045	3.50	.727	1.24		7.84
Red, " "	2.26	.53	3.48	.108	.649	1.539	5.74
Green, " "	3.71	.954	3.058	.80	1.213	.824	6.768
Blue, " "	5.68	1.244	3.755	1.181	1.513	.661	9.435
Yellow, " "	8.375	2.075	3.46	.337	2.42	.413	11.835

TABLE III.

S. Comparison of fluctuation time with adaptation time using colors and grays. Fluctuation: showing that visibility and invisibility have characteristic adaptation and recovery peculiarities.

Stimulus	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Invis.: Vis.	Period
Gray, 2x2 cm.	3.47	1.053	2.31	.533	1.502		5.78
Red, " "	1.333	.338	2.8	.527	.4761	2.025	4.133
Green, " "	2.806	.506	2.431	.575	1.154	.866	5.237
Blue, " "	3.2	.836	1.779	.326	1.799	.562	4.979
Yellow, " "	5.576	1.257	1.238	.537	4.504	.221	6.814

TABLE IV.

Ge. Comparison of fluctuation time with adaptation time using colors and grays. Fluctuation: showing that visibility and invisibility have characteristic adaptation and recovery peculiarities.

Stimulus	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Invis.: Vis.	Period
Gray, 2x2 cm.	3.715	.693	2.028	.917	1.832		5.743
Red, " "	1.566	.383	5.95	1.608	.2632	3.799	7.516
Green, " "	3.17	.96	5.6	2.41	.566	1.767	8.77
Blue, " "	4.471	1.157	5.042	1.142	.886	1.127	9.513
Yellow, " "	7.2	1.563	1.354	.355	.288	.188	8.554

TABLE V.

F. Comparison of fluctuation time with adaptation time using colors and grays. Fluctuation: showing that visibility and invisibility have characteristic adaptation and recovery peculiarities.

Stimulus	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Invis.; Vis.	Period
Gray, 2x2 cm.	3.8066	.786	2.54	.466	1.498		6.3466
Red, " "	2.4812	.287	3.362	.568	.737	1.355	5.843
Green, " "	3.55	.462	2.85	.443	1.245	.802	6.40
Blue, " "	3.586	.653	2.793	.7	1.283	.779	6.379
Yellow, " "	4.716	.791	2.141	.366	2.202	.453	6.857

Attention is called again to the fact that, as would be expected from the compensation theory, red and blue have longer phases of invisibility and shorter phases of visibility, respectively, than green and yellow. The relative value of the invisibilities as compared with the visibilities in each case is expressed by the ratio invisibility : visibility.

(2) *Adaptation.* To test the correspondence of these results with those obtained from adaptation, sheets of colors of the same make were placed behind lightly frosted glass and observed at distances ranging from 2-3 meters. Just how much the intensity was lowered by these conditions we are not able to say,—probably not one half. This does not matter, however, so long as each color was tested under precisely the same conditions, since only comparative values were wanted. The following results were obtained:

Obs. *G.* Distance: 235 cm. Time unit: 1 sec.

Red	41
Green	55
Blue	78
Yellow	263

Because of the severe eye-strains, the intensity was further reduced for *F* by placing the color 11 cm. behind the frosted glass.

Obs. *F.* Distance: 235 cm. Time unit: 1 sec.

Red	25
Green	41
Blue	58
Yellow	225

For *S*, the color was placed 19 cm. behind the frosted glass.

Obs. *S.* Distance: 300 cm. Time unit: 1 sec.

Red	19
Green	52
Blue	160
Yellow	196

The order is the same as was obtained in the fluctuation experiments; and a comparison of the Tables will show that a rough correspondence holds in the ratios sustained between the phases of visibility and the adaptation times in each case.

It may be objected that the colors used were not standardized. We are, however, not attempting to state results for standard colors. Our sole aim is to show correspondence between adaptation and fluctuation. This has been accomplished by using identical colors in the two sets of experiments. It could have been done no better, we believe, by using standard colors.

(c) *Combinations of stimulus and background that influence adaptation time correspondingly influence fluctuation time.* (1) *Fluctuation.* For this point so far the Masson disk has been used. From all the colors tried as background, light greenish blue (Hering), yellowish green (Milton-Bradley), yellow (Milton-Bradley), orange (Hering), gray, and in one case dark red (Milton-Bradley) were selected for the following Tables. The stimulus strips were 2 mm. x 5 mm., and were placed 8 mm. apart along the radius. They were, with one exception, of Hering red.

This method we consider very unsatisfactory. In the first place, results never stand out so clearly with the Masson disk as when the system is at rest: judgments are difficult; distractions are many, and gradations of intensity, neither so constant nor even so delicate, can be obtained. And, secondly, as our disks were made, the stimulus color was rendered liminal by mixing with the color of the background rather than with a gray of its own brightness. If we take, for example, a red stimulus upon a light blue background, the effect obtained was a faintly reddish blue upon a blue background, slightly differing from it in brightness. But even this approximation to the desired conditions was sufficient to vary the phase of visibility to a rough correspondence with the results obtained with a similar combination of stimulus and background in the adaptation experiments.

(2) *Adaptation.* Here, likewise, red at *full intensity* disappears most readily upon the light blue; not quite so readily upon the gray used; and never entirely goes into the background, although the color is lost periodically, upon the orange, yellow, and yellowish green. Yellow on dark red is peculiarly persistent.

In addition to the combinations here used, we have tried a number both of grays and of colors, and are satisfied that whatever alters the conditions for adaptation correspondingly alters the conditions for fluctuation.

(d) *Method of variation of areas.* (1) *Fluctuation.* This

TABLE VI.

Ga. Combinations of stimulus and background that influence adaptation time correspondingly influence fluctuation time. Fluctuation.

Stimulus	Background	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 2x5 mm.	Light Blue	2.287	.681	3.362	.631	.6803	5.649
" " "	Yellow	4.609	.1141	2.78	.600	1.6856	7.388
" " "	Orange	4.709	.1127	2.936	.663	1.600	7.645
" " "	Yellowish Green	4.130	1.161	2.715	.800	1.521	6.845
" " "	180° Engine Gray + 180° Velvet Black	3.615	1.076	3.268	1.1	1.106	6.893
Yellow, 2x5 mm.	Dark red	6.512	1.012	3.887	.912	1.675	10.399

TABLE VII.

F. Combinations of stimulus and background that influence adaptation time correspondingly influence fluctuation time. Fluctuation.

Stimulus	Background	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 2x5 mm.	Light blue	2.9	.398	3.164	.58	.969	6.064
" " "	Yellow	4.73	.52	2.96	.4	1.598	7.69
" " "	Yellowish Green	4.4	.717	3.2	.37	1.375	7.60
" " "	180° Engine Gray + 180° Velvet Black	2.9	.292	2.95	.628	.983	5.85

method was tried both upon the Masson disk and with the opal glass plate as a background. The results in both cases were unquestionable; but, as before, those given by the stationary system were much the more satisfactory and much the more clearly cut. Because of this, and chiefly because the disk did not permit enough variation of area, the Masson disk will be omitted from further consideration in this paper.

A stimulus was obtained upon the opal glass plate by light coming from a bank of lamps behind it, passing first through a plate of frosted glass, then through the opal glass itself. The magnitude of the stimulus was regulated by a card-board diaphragm behind the screen; its intensity, by varying the distance of the lamps, also by means of a curtained window in front. This photometric arrangement provided a very sensitive means of obtaining a just noticeable stimulus. After the initial adjustment was made, great care was taken that the illumination of the background should remain constant throughout the experiment.

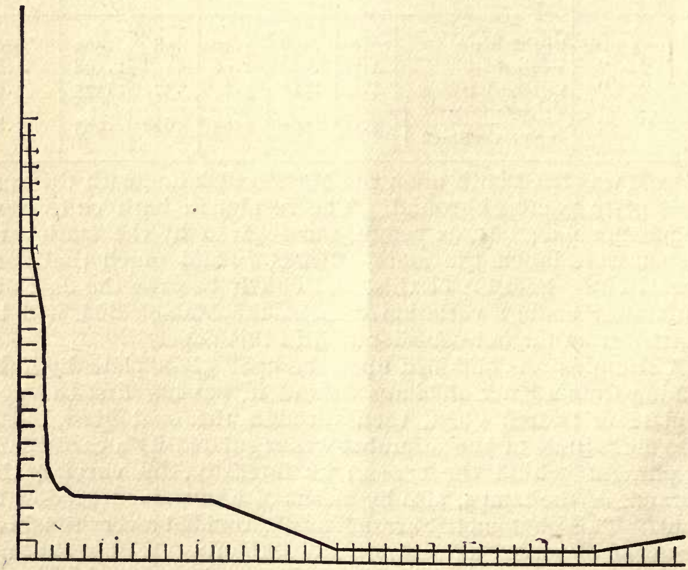
TABLE VIII.

F. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with increase of area.

Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
2x 2 mm.	16.86	4.83	.8	.28	21.075	17.66
4x 4 "	12.93	3.53	1.15	.38	11.24	14.08
6x 6 "	10.78	3.8	2.9	.83	3.71	13.68
8x 8 "	5.65	1.53	2.76	.52	2.23	8.41
10x10 "	4.74	1.32	2.34	.63	2.023	7.09
12x12 "	4.22	.97	2.72	.57	1.551	6.94
14x14 "	4.35	1.29	3.2	.46	1.359	7.55
16x16 "	3.96	1.22	2.918	.59	1.360	6.878
6x 6 cm.	3.73	1.11	5.2	.77	.717	8.93
10x10 "	.81	.23	9.65	2.8	.073	10.46
14x14 "	.8	.5	29.46	4.66	.027	30.26
18x18 "	.85	.45	40.25	2.25	.021	40.10
22x22 "	1.4	No reappearance.				

For *F*, beginning at areas ranging from 10 cm. x 10 cm.—14 cm. x 14 cm. in the different records, it was noticed that only the edge of the lower left hand corner and left side reappeared.

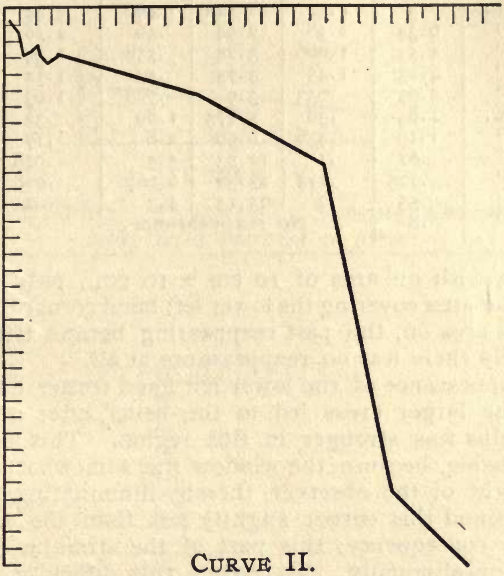
The results of this Table have been thrown into the form of



CURVE I.

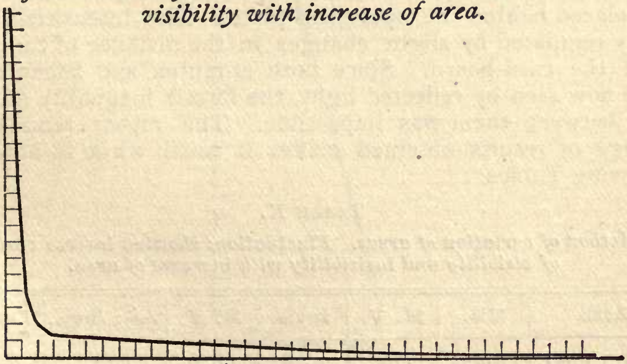
Curve for visibility. TABLE VIII. *Showing decrease of visibility with increase of area.*

a curve. The dimensions of the stimulus are laid off along the abscissa, millimeter for millimeter; the time values along the ordinate, on the scale of 1 second to 5 millimeters. The last and more horizontal part of the curve for visibility represents the reappearance of the edge of the left side and the lower left hand corner.



CURVE II.

Curve for invisibility.[1] TABLE VIII. *Showing increase of invisibility with increase of area.*



CURVE III.

Curve for visibility : invisibility. TABLE VIII. *Showing decrease with increase of area.*

[1] In this and the following curves invisibility is platted as a negative quantity.

TABLE IX.

Ga. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with increase of area.

Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
2x 2 mm.	7.3	1.31	2.122	.466	3.44	9.422
4x 4 "	6.34	1.38	2.94	.46	2.16	9.28
8x 8 "	4.53	1.066	3.24	.558	1.39	7.77
12x12 "	4.23	1.45	3.75	.53	1.12	7.98
16x16 "	4.03	.933	3.9	.708	1.03	7.93
6x 6 cm.	1.83	.58	5.675	1.89	.32	7.505
10x10 "	1.19	.436	6.96	2.8	.17	8.15
16x16 "	.61	.1	12.53	3.3	.048	13.14
26x26 "	.725	.175	25.36	6.067	.028	26.085
34x34 "	.55	.2	25.13	4.3	.021	25.68
42x38 "	.8	No reappearance.				

For *Ga*, with an area of 10 cm. x 10 cm., only about one third of the area covering the lower left hand corner reappeared. From that area on, the part reappearing became less and less, until finally there was no reappearance at all.

The reappearance of the lower left hand corner alone in the case of the larger areas led to the belief, after a time, that the stimulus was stronger in this region. This was all the more probable, because the window was somewhat above and to the right of the observer, thereby illuminating the background around this corner slightly less than the rest of the field. In consequence, this part of the stimulus stood out slightly supraliminally. To obviate this difficulty, stimuli of Hering gray, no. 27, were pasted upon engine-gray card-board and placed behind the opal glass plate. The intensities were easily regulated by slight changes in the distance of the plate from the card-board. Since both stimulus and background were now seen by reflected light, the former inequality of relation between them was impossible. The rather remarkable change of results obtained makes it worth while to note the following Tables.

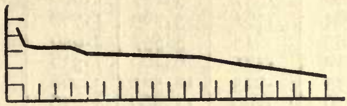
TABLE X.

F. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with increase of area.

Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
3x 3 mm.	4.435	.742	4.285	.835	1.035	8.72
6x 6 "	3.372	.854	6.772	1.218	.498	10.144
10x10 "	3.327	.5	11.562	1.937	.287	14.889
20x20 "	3.31	.71	12.975	1.84	.255	16.285
25x25 "	2.962	.427	14.36	2.812	.206	17.322
6x 6 cm.	1.533	.333	38.00	.723	.0403	39.533
10x10 "	1.145	No reappearance.				

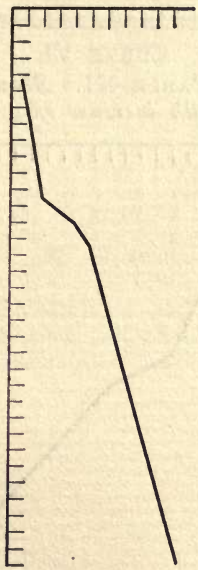
Curves were plotted from these results to compare with those obtained from Table VIII.

It will be noticed that this series began with an area of 3 mm. x 3 mm. In the former case, it was 2 mm. x 2 mm.



CURVE IV.

Curve for visibility. TABLE X. *Showing decrease of visibility with increase of area.*



CURVE V.

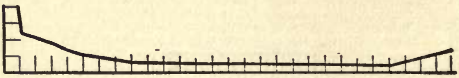
Curve for invisibility. TABLE X. *Showing increase of invisibility with increase of area.*

TABLE XI.

Ga. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with increase of area.

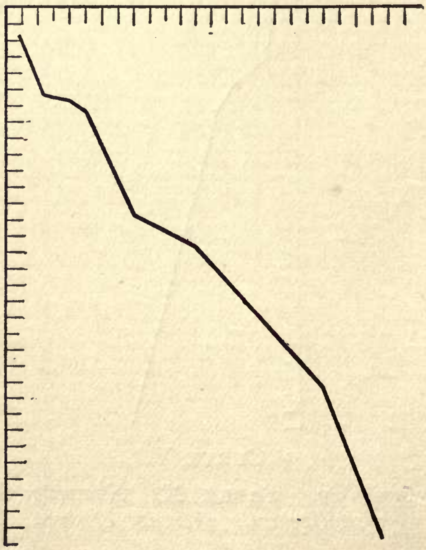
Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
4x 4 mm.	4.466	1.26	1.853	.406	2.41	6.319
6x 6 "	2.385	.910	2.934	.828	.812	5.319
12x12 "	2.000	.537	5.257	1.600	.380	7.257
16x16 "	1.984	.761	5.269	1.768	.376	7.253
20x20 "	1.453	.615	5.557	2.050	.261	7.010
25x25 "	1.122	.321	6.100	1.538	.183	7.222
4x 4 cm.	.775	.225	12.583	3.266	.061	13.358
6x 6 "	.716	.200	14.460	4.216	.049	15.176
10x10 "	.632	.197	23.100	3.500	.027	23.732
12x12 "	.590	.284	33.866	7.445	.017	34.456
14x14 "	1.5	No reappearance.				

The following curves represent the results of the preceding Table. The first area used is 4 mm. x 4 mm.



CURVE VI.

Curve for visibility. TABLE XI. *Showing decrease of invisibility with increase of area.*



CURVE VII.

Curve for invisibility. TABLE XI. *Showing increase of invisibility with increase of area.*

TABLE XII.

Ge. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with variation of area.

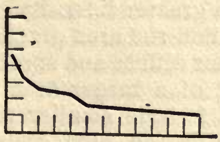
Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
3x 3 mm.	5.43	1.5	3.192	1.169	1.732	8.622
6x 6 "	3.14	1.033	4.3	.930	.730	7.44
10x10 "	2.469	.953	6.09	.305	.305	8.559
20x20 "	2.16	.72	15.683	4.016	.137	17.843
25x25 "	1.185	.255	18.342	3.342	.064	15.75
6x 6 cm.	.7	.133	27.75	5.85	.025	28.45
10x10 "	1.2	No reappearance.				

TABLE XIII.

S. Method of variation of areas. Fluctuation: showing inverse variation of visibility and invisibility with increase of area.

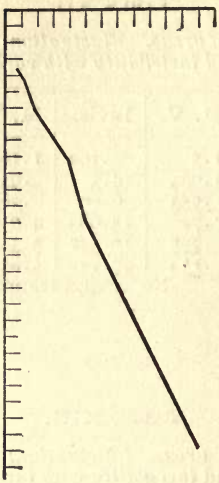
Area	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
3x 3 mm.	4.683	1.26	2.28	.633	2.05	6.963
6x 6 "	3.66	.686	2.26	.626	1.619	5.92
10x10 "	2.876	.557	2.33	.495	1.234	5.206
16x16 "	2.521	.643	2.57	.556	.980	5.091
20x20 "	2.23	.709	2.80	.668	.796	5.030
4x 4 cm.	2.08	.625	2.98	.565	.697	5.06
8x 8 "	2.288	.594	3.805	1.047	.600	6.093
12x12 "	2.03	.523	5.361	1.230	.378	7.391
16x16 "	1.7	.514	12.9	2.385	.131	14.600
18x18 "	1.5	No reappearance.				

The averages of the visibilities and invisibilities of Tables X, XI, XII, and XIII were plotted up to the area 6 cm. x 6 cm., the last reappearance recorded for *F* and *Ge*.



CURVE VIII.

Curve for visibility. Averaged from Tables X, XI, XII, and XIII. *Showing decrease of visibility with increase of area.*



CURVE IX.

Curve for invisibility. Averaged from Tables X, XI, XII, XIII. *Showing increase of invisibility with increase of area.*

It will be noticed, in the above Tables, that the area at which fluctuation ceases has been decreased to one-fourth in the one case and to one-eighth in the other. This, we believe, is due solely to the inequality in intensity of the stimulus obtained by the former method, for it will be observed that the area at which the stimulus began to recur in parts in the former Tables nearly coincides with that at which fluctuation ceased in the latter.

It will be seen, also, that in the case of the smaller areas the phases of visibility have been decreased and the phases of invisibility increased. Sufficient explanation for this result can be found, most probably, in the different conditions for adaptation present in the two cases. It will be well, at least, to point them out.

(*a*) Although of no greater intensity, the stimulus area was more sharply defined than the area given by the reflected light. The latter was somewhat diffuse and spreading, and to a certain degree gave the effect of a larger area. This slight change would be appreciable for the smaller areas, but not for the larger. (*b*) The side of the opal glass used for the background in the former case was polished and shining. This was trying to the eyes of the observer, the strain relieving itself in increased eye-movement and blinking. The side used in the latter case was dull and chalky, and produced no particular discomfort. (*c*) In the former case, the minimal difference to

be adapted out was between a bright white background and a still brighter stimulus. In the latter case, it was between a dull, chalky background and a darker stimulus. Just what effect this difference would have on adaptation we are not able to state. It seems reasonable to believe, however, that the process would not be uniform at all points in the white-black series. In fact records were obtained indicating that, in general, this is true; unfortunately, however, they were made early in the work, and were not arranged for a particular confirmation of results under these precise conditions. As nearly as can be determined from them, planned as they were, the process is more rapid at the extremes of the white-black series (indicated by the shorter phases of visibility here obtained) than in the mid-region of neutral grays. The stimulus just noticeably lighter than a black background, too, seems to give slightly shorter phases of visibility than a stimulus just noticeably darker than a white background. It will be understood that these results are not intended to apply to adaptation any further than for the obliteration of just noticeable differences. But from the data we may draw the very general conclusion that the value of just noticeable differences for adaptation, even in the white-black series, depends upon the sort of combination used.

It is important to note that while Lange[1] finds approximate equality in the periods obtained from three sense departments, and argues therefrom a central origin, it is found here that a change of conditions so slight as to have passed unnoticed, had not the results demanded investigation, brings a wide range ot variability, although not even a change in the retinal elements stimulated is involved, *i. e.*, both series of combinations of stimulus and background are in the white-black series.

Another point noticeable in these records, and throughout the work in general, is the large mean variation. This is especially obvious when large areas are used, or whenever from any cause either visibility or invisibility approaches infinite value. It is due, chiefly, to one or two very long phases of visibility or very short phases of invisibility, or conversely; the phenomena depending upon which extreme of the phase variation one is considering. Slaughter[2] believes that there is a connection between these recurring long phases of visibility, obtained with stimuli of the usual order, and the Traube-Hering waves. It seems, however, much more probable that their immediate condition is to be found in eye-movement. In unsteady fixation, the eye oscillates, *i. e.*, in recovering fixation,

[1] *Philosophische Studien*, IV, 390.
[2] *Op. cit.*

it overdoes, swinging to the other side and back again, etc. Eye-movements come in groups. One or more of these groups occurring within a phase of visibility, will prolong it very much; or falling within a phase of invisibility will shorten it proportionately. These facts are brought out plainly in the records for eye-movement.

That extensive voluntary eye-movement will not cause the reappearance of the faded-out stimulus, provided sufficiently large areas are used, was confirmed for *Ga* and *S*. An area of opal glass 30 cm. square was made just noticeably red by light transmitted through red paper covering its back. Three fixation points were made the apices of an equilateral triangle, circumscribed about the centre of the plate. The observer, seated at a distance of 98 cm., allowed the color to adapt out, and then shifted his eyes along the sides of the triangle from fixation point to fixation point in order. The following results were obtained:

Ga. With 2 cm. eye-movement (in each direction) . . . . . . Slight reappearance at edges only.

With 3.3 cm. eye-movement. . . . . Began to get a wash of color farther in from the edges.

With 4 cm. eye-movement. . . . . Color returned a little more perceptibly over central area.

S reported no change at all until 4.9 cm. of eye-movement in each direction were reached. Then there was a slight wash of color, pretty much over the whole area. Had he observed more closely, he probably would have noticed the changes at the edges sooner than this.

The intensity of the stimulus was increased considerably above the limen, and the same method carried out with similar results. A larger area, however, had to be used with the same range of movement.

These facts speak strongly against innervation as the cause of the reappearance of the adapted out stimulus. Much more plausible does it seem that restoration comes about on account of actual change of stimulation of the adapted elements.[1]

(2) *Adaptation*. The following Tables show the effect of variation of area for recognized adaptation phenomena. The combinations of stimulus and background chosen are the most favorable for intermittence. Fluctuations of intensity may be had from any combination, but complete disappearances take place most readily with those here selected. The eye-strain involved and the consequent unsteady fixation make the phenomenon somewhat difficult to obtain.

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[1] Together with the supplementary process mentioned but not specified above.

TABLE XIV.

Ga. Method of variation of areas. Adaptation: showing inverse variation of visibility and invisibility with increase of area.

Stimulus	Background	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 1x 5 mm.	Blue	No disappearance.					
" 2x 5 "	"	4.64	.98	1.175	.325	3.95	5.815
" 5x 5 "	"	2.77	.601	4.19	1.16	.66	6.96
" 10x10 "	"	1.4	.34	4.44	1.24	.31	5.84
" 2x35 "	"	1.68	.58	3.35	1.09	.5	5.03
Hering Gray, (no. 27) 1x 5 mm.	Hering Gray, (no. 33)	No disappearance.					
" 2x 5 "	"	27.915	1.423	.54	.223	51.694	28.455
" 5x 5 "	"	9.450	2.617	1.568	.57	6.057	11.018
" 10x10 "	"	6.787	2.25	2.275	.325	2.983	9.062
" 2x35 "	"	10.36	3.07	1.485	.285	6.976	11.846

TABLE XV.

E. Method of variation of areas. Adaptation: showing inverse variation of visibility and invisibility with increase of area.

Stimulus	Background	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 1x 5 mm.	Blue	9.5627	2.66	1.075	.175	8.895	10.637
" 3x 5 "	"	4.237	1.07	1.381	.281	3.067	5.618
" 7x10 "	"	1.878	.255	2.863	.594	.656	4.741
" 1x 5 "	Gray	3.542	1.071	10.471	2.514	.3383	14.013
" 5x 5 "	"	2.06	.480	8.55	1.71	.2409	10.61

F. ADAPTATION IS RENDERED INTERMITTENT CHIEFLY BY EYE-MOVEMENT.

"Even in fixation intended to be constant, as in the present investigation, it is not likely that the eye was motionless for the eight to thirty seconds during which the experiment lasted, as McAllister has recently pointed out that the eye is seldom at rest for one-ninth of a second continuously. At least it would be most unlikely that it should be absolutely at rest for so long a period as twenty seconds and then move unconsciously at the end of that time." [1]

The inference contained in the above quotation is that, if eye-movement causes relief of the adapted elements sufficient to bring about reappearance when complete adaptation has once set in, disappearance should never have occurred;

[1] W. B. Pillsbury: *The Journal of Philosophy, Psychology, and Scientific Methods*, II, 272. Review of *Zur experimentellen Kritik der Theorie der Aufmerksamkeitsschwankungen*, by B. Hammer.

for the eye is moving almost continuously, and each movement should have relieved the adaptation that had taken place previous to it. Pillsbury has, however, probably not considered that range of movement is a factor as well as frequency. If the eye moved nine times a second with sufficient range, there probably never would be noticeable adaptation for small areas. How far this supposition is from the facts, however, is shown by our results. The average interval between movements extensive enough to produce a noticeable shift of the after-image in either the horizontal or vertical plane, viewed at a distance of 1 meter (and certainly smaller movements could scarcely be considered to bear upon the point in question), ranges from $\frac{4}{5}$ sec.-$2\frac{1}{4}$ sec. The average time between movements shifting the after-image 2 mm. in either plane ranges from $1\frac{1}{2}$ sec.-$2\frac{1}{2}$ sec.; 4 mm., from $2\frac{1}{7}$ sec.-48 sec.; 6 mm., from $3\frac{1}{3}$ sec.-96 sec., etc. Now it will be remembered that the movements in each plane came in groups of two and three, so that these intervals in most cases should be so much multiplied. According to this account, there seems to be ample opportunity for adaptation to take place, when range of movement is taken into consideration as well as frequency. Movements as small as those referred to by McAllister would probably produce some effect in delaying adaptation; but complete restoration before the stimulus has adapted out, or reappearance after it has disappeared, is doubtless caused by groups of movements of considerable range.

The range of movement required will, of course, depend upon the stimulus area used. When the area is very small, Pillsbury's inference holds; there is no disappearance. The restoration afforded by eye-movement here cancels the effect of adaptation before disappearance takes place. This is one of the points brought out by our method of areas. On the other hand, with areas varying from 10 cm. x 10 cm. — 14 cm. x 14 cm., the range of movement for our observers was not great enough ever to produce reappearance. And with still larger areas, extensive voluntary movements did not suffice even to revive the lost sensation.

We do not assert that the statement quoted, considered as a criticism of Hammer's article, is not well grounded. This article is chiefly suggestive. But, on the other hand, it is only fair to remember that it requires positive knowledge to overthrow as well as to establish a theory. Both statement and criticism should, with equal care, be based upon ample investigation. That eye-movement, blinking, etc., interfere with the course of adaptation is not a recently discovered fact, nor is it a closed subject. Local adaptation still presents a fruitful field for research.

With the help of the data submitted in this article, we trust that no intrinsic difficulty will be found in the conception that adaptation is rendered intermittent by eye-movement. Aside from this, too, there remains, further to strengthen the theory, the supplementary factor (not yet specified) which works in conjunction with the relief afforded by a shift of the adapted elements into a region of different stimulation.

For the investigation of eye-movement, a method had to be selected that would not be objectionable to the observers, and would not interfere with the normal course of the phenomenon either mechanically or by way of distraction. The shifting of the negative after-image during fixation afforded a method somewhat rough, but adequate for our purpose. Colored strips, 5 mm. x 40 mm., were used as stimuli. They were pasted on a background of white card-board, with the shorter dimension in the plane in which the eye-movement was to be investigated. The determination of frequency then became merely a matter of recording the appearance of the after-image to the right or left or above or below the stimulus, separate series being made for both planes. For the determination of range of movement, narrow strips of paper of the same brightness as the background were placed successively 2, 4, 6, 8, etc., mm. from the stimulus, and only those movements recorded that caused the after-image to shift to or beyond these strips. The strips were so inconspicuous as not to attract the eye away from the fixation point; still, it was not difficult to judge when the after-image reached, or passed beyond them. They were always used, also, when frequency alone was to be determined, in order that the same conditions might prevail throughout. Some periods were given up wholly to the investigation of eye-movement alone, thus determining the type in general; while again the eye-movement tracing was alternated with the corresponding fluctuation tracing, in order to establish a more immediate connection between the eye-movements in either plane and the phases of visibility and invisibility in that plane. Doubtless, it would have been better to have the eye-movement recorded while the fluctuation was in progress, could this have been done without interfering with the normal course of the phenomenon. As it was, however, enough results were obtained to render conclusions safe as to the type of the observer.

The stimuli in both the eye-movement and fluctuation experiments were of the same dimensions, and were arranged in precisely the same way. The distance of the observer, throughout, was 1 meter. The color of the stimulus was selected with reference to the vividness of the after-image for the particular observer. Milton-Bradley standard green was used for *S*, *Ga*,

3

Ge, while red of the same make gave the best results for *F*. The expression: 'stimulus vertical' will be used when the longer dimension of the strip is placed in the vertical plane, and 'stimulus horizontal' for the corresponding arrangement in the horizontal plane.

The following results were obtained:

(a) *Eye-movement in the horizontal and vertical planes.*

S. Length of observation: 97 sec.

Stimulus vertical.

Strips 2 mm. distant. Recorded all,	55
All reaching to strips 2 mm. distant,	26
“ “ “ “ 4 “ “	11
“ “ “ “ 6 “ “	4

Stimulus horizontal.

Strips 2 mm. distant. Recorded all,	39
All reaching to strips 2 mm. distant,	21
“ “ “ “ 4 “ “	9
“ “ “ “ 6 “ “	2

The results here show greater range and greater frequency in the horizontal plane. The records also demonstrated that the recovery was quicker in this plane.

Ge. Length of observation: 94 sec.

Stimulus vertical.

Strips 2 mm. distant. Recorded all,	46
All reaching to strip 4 mm. distant,	40
“ “ “ “ 6 “ “	14
“ “ “ “ 8 “ “	7
“ “ “ “ 10 “ “	2

Stimulus horizontal.

Strips 2 mm. distant. Recorded all,	30
All reaching to strip 2 mm. distant,	25
“ “ “ “ 4 “ “	14
“ “ “ “ 6 “ “	0

It will be noticed that the excess of range in the horizontal plane in this Table is considerably greater than the excess of frequency. There is quicker recovery also in the horizontal plane.

Ga. Length of observation: 96 sec.

Stimulus vertical.

Strips 2 mm. distant. Recorded all,	35
All reaching to strips 2 mm. distant,	31
“ “ “ “ 4 “ “	2
“ “ “ “ 5 “ “	1

Stimulus horizontal.

Strips 2 mm. distant. Recorded all,	81
All reaching to strips 2 mm. distant,	9
“ “ “ “ 4 “ “	0

This Table shows greater frequency in the vertical and greater range in the horizontal plane. In the next Table the experiments for range were not carried out. The following averages for frequency were obtained:

F. Length of observation, 104 sec.

Stimulus vertical,	29
" horizontal,	17

Towards the end of the hour, for each observer, the records showed increase of eye-movement, as the result of fatigue.

(b) *Fluctuation with vertical and horizontal arrangement of the stimulus.*

The following are the results obtained for the fluctuation experiments. The stimulus was rendered liminal by being placed behind a plate of opal glass.

TABLE XVI.

S. Fluctuation with vertical and horizontal arrangement of the stimulus. Showing how arrangements that favor maximal and minimal interference with adaptation affect the phases of visibility and invisibility.

Stimulus	Arrangement	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 5x40 mm.	Vertical	5.3545	1.027	2.4727	.690	2.165	7.8272
" " "	Horizontal	3.0733	.426	2.7066	.666	1.135	5.7799
Red, " "	Vertical	3.152	.917	1.641	.453	1.9207	4.793
" " "	Horizontal	2.358	.452	2.436	.621	.968	4.794
Green, " "	Vertical	4.986	1.06	1.493	.413	3.340	6.479
" " "	Horizontal	3.260	.526	2.546	.786	1.2804	5.806
Yellow, " "	Vertical	5.0611	.911	1.588	.511	3.187	6.6491
" " "	Horizontal	4.642	.580	2.542	.371	1.825	7.1856

TABLE XVII.

Ge. Fluctuation with vertical and horizontal arrangement of the stimulus. Showing how arrangements that favor maximal and minimal interference with adaptation affect the phases of visibility and invisibility.

Stimulus	Arrangement	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 5x30 mm.	Vertical	3.873	.873	2.32	.933	1.669	6.193
" " "	Horizontal	3.825	.983	3.458	1.075	1.135	7.283
" 5x40 "	Vertical	4.006	1.293	2.526	.733	1.585	6.533
" " "	Horizontal	1.407	.268	4.423	1.153	.3181	5.830
" 5x50 "	Vertical	4.353	.822	2.700	.868	1.6123	7.053
" " "	Horizontal	2.700	1.071	3.285	.778	.8217	5.985
Green, 5x40 "	Vertical	4.400	1.054	4.981	1.172	.8833	9.381
" " "	Horizontal	2.663	.490	5.481	1.154	.4857	8.144

TABLE XVIII.

Ga. Fluctuation with vertical and horizontal arrangement of the stimulus. Showing how arrangements that favor maximal and minimal interference with adaptation affect the phases of visibility and invisibility.

Stimulus	Arrangement	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 10x50 mm.	Vertical	2.655	.644	6.422	1.333	.4135	9.077
" " "	Horizontal	3.336	.763	5.545	1.418	.6016	8.881
Yellow, 2x40 "	Vertical	3.807	1.115	3.223	.915	1.181	7.030
" " "	Horizontal	6.96	1.987	2.45	.801	2.8408	9.41

TABLE XIX.

F. Fluctuation with vertical and horizontal arrangement of the stimulus. Showing how arrangements that favor maximal and minimal interference with adaptation affect the phases of visibility and invisibility.

Stimulus	Arrangement	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 5x40 mm.	Vertical	4.8685	1.29	3.495	.775	1.392	8.3635
" " "	Horizontal	3.038	.646	3.753	1.092	.809	6.791

(c) *Adaptation with vertical and horizontal arrangement of the stimulus.*

That the same arrangement is effective with stimuli at full intensity was confirmed by experiments upon *Ga.* A strip of Hering red, 5 mm. x 30 mm., was pasted on a square of Hering light blue, 20 cm. x 20 cm., and viewed at a distance of 2 meters.

TABLE XX.

Ga. Adaptation with vertical and horizontal arrangement of the stimulus. Showing the interference caused by the vertical and horizontal arrangements.

Stimulus	Arrangement	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 5x30 mm.	Vertical	2.24	.671	4.014	.914	.558	6.254
" " "	Horizontal	3.987	.727	3.775	.887	1.056	7.762

G. CORRESPONDENCE OF FLUCTUATION WITH ADAPTATION IN INDIRECT VISION.

(a) *Fluctuation.* In the fluctuation experiments in indirect vision, the stimuli were rendered liminal by the use of the opal glass plate, as before. The observer was seated at a distance of 1 meter and given a fixation point in the median line. It

will be noticed in these results, as also in the Tables for the method of variation of areas, that the average phase of visibility increases slightly at the end of the Table. The reason is that in each tracing the phase of visibility is greatest at the beginning and decreases considerably towards the end. Now in the last series of the Table there are few and, at the very last, no phases of visibility to average with these maximal first phases; consequently the curve rises a little at the lower end. For the same reason, the mean variation for both visibility and invisibility increases towards the end of the Table.

The results obtained are given in the following Tables. The points to be noticed are the effects of variation of area and passage of stimulus towards the periphery.

TABLE XXI.

Ga. Correspondence of fluctuation with adaptation in indirect vision. Fluctuation: showing the effect of increase of area and passage of stimulus towards the periphery.

Stimulus	Distance from fixation	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 8x8 mm.	0 cm.	2.335	.67	2.38	.485	.985	4.715
" " "	4 "	1.527	.383	3.52	.993	.434	5.047
" " "	8 "	1.13	.345	7.35	2.212	.153	8.48
" " "	12 "	1.08	.39	8.73	2.157	.123	9.81
" " "	20 "	.566	.1	13.38	4.8	.0423	13.946
" " "	24 "	.633	.06	34.53	12.	.018	35.163
" 6x6 cm.	0	1.49	.64	6.33	1.73	.235	7.82
" " "	4 "	1.177	.355	8.411	2.07	.140	9.588
" " "	8 "	.628	.214	10.685	2.514	.0588	11.312
" " "	12 "	.625	.175	23.125	3.875	.0265	23.75
" " "	20 "	.250	.03	43.25	7.282	.0057	43.75
" " "	24 "	.2	No reappearance.				

TABLE XXII.

F. Correspondence of fluctuation with adaptation in indirect vision. Fluctuation: showing the effect of increase of area and passage of the stimulus towards the periphery.

Stimulus	Distance from fixation	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 5x5 mm,	0 cm.	4.12	.83	2.41	.50	1.709	6.53
" " "	8 "	1.671	.507	4.514	.102	.370	6.185
" " "	12 "	1.187	.5	9.625	2.28	.122	10.812
" " "	20 "	.433	.123	22.25	4.82	.0194	22.683
" 6x6 cm.	0 "	2.35	.46	4.77	1.13	.492	7.12
" " "	8 "	2.24	.65	14.04	3.158	.1592	16.28
" " "	20 "	1.5	No reappearance.				

TABLE XXIII.

Ge. Correspondence of fluctuation with adaptation in indirect vision. Fluctuation: showing the effect of increase of area and passage of stimulus towards the periphery.

Stimulus	Distance from fixation	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Gray, 6x6 mm.	0 cm.	3.975	1.21	4.187	1.33	.949	8.162
" " "	8 "	2.1875	1.1	8.4	.24	.2604	10.5875
" " "	12 "	1.128	.285	1.528	3.045	.09785	12.656
" " "	20 "	.79	.25	11.04	.665	.0715	11.83
" " "	28 "	.5	.21	11.728	2.971	.0426	12.228
" " "	34 "	.375	.1	11.987	2.446	.0312	12.362
" " "	43 "	.5	.2	44.9	9.62	.0111	45.4
" 6x6 cm.	0 "	.62	.22	22.75	4.64	.0272	22.97
" " "	8 "	.7	.2	42.6	9.89	.0151	43.3
" " "	12 "	1.	No reappearance.				

(b) *Adaptation.* That stimuli at full intensity show the same law of inverse variation of visibility: invisibility from direct vision towards the periphery was verified by *Ga.* Hering standard red upon a background of engine-gray card-board (neutral shade) was used.

TABLE XXIV.

Ga. Correspondence of fluctuation with adaptation in indirect vision. Adaptation: showing the effect of passage of stimulus towards the periphery.

Stimulus	Distance from fixation	Vis.	M. V.	Invis.	M. V.	Vis.: Invis.	Period
Red, 8x8 mm.	8 cm.	15.916	3.25	.2	.033	79.58	16.116
" " "	12 "	6.575	2.05	1.683	.475	3.907	8.258
" " "	20 "	4.293	1.13	2.656	.925	1.612	6.949
" " "	24 "	4.89	1.05	3.35	1.151	1.46	8.24
" " "	34 "	3.2	1.192	5.5	1.107	.581	8.7
" " "	42 "	2.9	.766	6.583	1.208	.440	9.73
" " "	50 "	2.33	.86	9.26	2.32	.240	11.56
" " "	60 "	.45	No reappearance.				

The adaptation times in indirect vision were also obtained for the same stimulus. The background in this case was, as before, the neutral engine-gray card-board. The time required completely to adapt out the stimulus was recorded. This, an adaptation experiment in its purest form, shows that the time required to adapt out the stimulus decreases as we go towards the periphery. One may suggest the following reasons why this decrease should occur:

(1) Decrease of the retinal stuff towards the periphery. This would certainly be true for colored stimuli.

(2) Since the eye is approximately spherical in form, and the aperture is near the front surface, one might expect less absolute change of stimulation area towards the periphery on account of eye-movement. Experiments to test the matter, by the same method as was used in direct vision, showed a marked decrease in the number of eye-movements recorded as the stimulus was moved towards the periphery. Whether this was because there was actually less range of movement of the after-image, or was due solely to the greater difficulty of observation, we are not able to state. The fact that there was a greater decrease in range than in frequency would seem to indicate that the effect was not wholly due to increased difficulty of observation.

(3) A further reason will be discussed when we deal with the fluctuation of after-images.

The observer sat with eyes closed and registration key up. The drum was started. At a signal the observation was begun and the key pressed down. When the color had adapted out, the key was released. The results were as follows:

Ga. Time unit: 1 sec.

Stimulus 8 cm. from fixation,	15.8
" 12 " " "	9.7
" 20 " " "	5.0
" 28 " " "	4.8
" 54 " " "	2.8

II. Cutaneous Stimuli.

(a) *Pressure.* Liminal pressure stimuli were applied to several observers, but no fluctuations were experienced. Very smooth cork wafers supporting minimal weights were used, and every care was taken to insure uniformly distributed, pure pressure sensations.

(b) *Electro-cutaneous.* Liminal electro-cutaneous stimulation was also tried. The tip of the tongue was selected as the area most sensitive to stimulation. Strips of very light tin foil (Christmas-tree foil) were used as electrodes. The moist surface of the tongue readily held these in place. There was no preliminary sensation of pressure or contact. The observer was not even able to tell that the strips were in place when the current was off. A Du Bois-Reymond sledge was chosen as giving the most easily regulated induction current. The observer was seated in a distant room, his head fixed in a head-rest, and the electrodes clamped in place. He was thus isolated from all noise and distracting influence. An electric button was near his hand by means of which he could signal to the experimenter and thus regulate the intensity of the stimulus. With care just noticeable stimuli were easily obtained; but no

fluctuations of intensity could be detected, although repeated attempts were made on a number of observers. It hardly seems possible that failure to obtain fluctuations could have been due to faulty conditions.

We submit these results hoping that, when they have been verified elsewhere, they will prove as decisive to others as they have been to us. We trust that in them ample evidence has been afforded that Lange advanced the theory of fluctuation of attention upon insufficient data. Indeed, that an attempt ever should have been made to gather together these discrete sense-phenomena under the head of 'fluctuation of attention' seems more the result of doctrinal development than of a thorough-going consideration of the phenomena themselves.

The Intermittence of Minimal Visual Sensations.

THE INTERMITTENCE OF MINIMAL VISUAL SENSATIONS

STUDIED FROM THE SIDE OF THE NEGATIVE AFTER-IMAGE

I

THE FLUCTUATION OF THE NEGATIVE AFTER-IMAGE

By C. E. FERREE, Lecturer in Psychology at Bryn Mawr College, late Assistant in Psychology at Cornell University

TABLE OF CONTENTS

I. Introduction

This paper is a continuation of a study published in this *Journal* in January, 1906.[1] In that article the fluctuation of minimal cutaneous and minimal visual stimuli was discussed. The absence of fluctuation for cutaneous stimuli was demonstrated by a series of experiments, upon a number of observers, with liminal pressure and electrical stimuli.[2] The fluctuation

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[1] C. E. Ferree: An Experimental Examination of the Phenomena usually Attributed to Fluctuation of Attention: XVII, 81.

[2] This part of the work has recently been repeated and extended by L. R. Geissler (Fluctuations of Attention to Cutaneous Stimuli, this *Journal*, XVIII, 1907, 309), and the previous results are confirmed. On the score of method it may be noted that a very thin, narrow strip of high-grade wrapping foil does better service than Christmas tree foil, and that the tongue should not be protruded, but allowed to lie

of minimal visual stimuli was explained as a phenomenon of adaptation. The thesis was maintained, first that adaptation is rendered intermittent chiefly through the influence of involuntary eye-movement; and secondly that eye-movement interferes with adaptation in two ways: it reduces the time of stimulation, and by shifting the retina into a region of different stimulation, it causes the restoration of the adapted elements.

The first of the effects just mentioned is obvious; but the second demands explanation. That eye-movement does restore the adapted retina can, in the present state of our knowledge of the phenomenon, scarcely be questioned;[1] but why a single eye-movement, consuming but a fraction of a second, or even a group of eye-movements, is able to restore a color or brightness that required a much longer time for adaptation, is not readily understood and needs to be investigated. Both the fact and its explanation have been the subject of much discussion in the history of visual theories. This discussion will be touched upon only briefly. It is not our purpose here to give a detailed account of visual theories. That will be attempted in a later paper. The object at this time is briefly to state such phases of visual theory as will be sufficient to introduce our problem. We find, in general, two main types of theory: the one represented by Fechner,[2] Helmholtz,[3] Fick and Gürber, etc., called the theory of fatigue; and the other represented by Plateau,[4] Hering,[5] G. E. Müller,[6] and others, usually called the theory of antagonistic visual processes, or, when the after-effect of stimulation is more especially regarded, the oscillatory theory.

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naturally upon the floor of the slightly opened mouth, with its edges pressing lightly against the lower teeth and lip.

[1] See Fechner, Pogg. Ann., XLIV, 1838, 525; Helmholtz, Physiol. Optik, 1896, 510; Fick and Gürber, v. Graefe's Archiv, XXXVI, 2, 1890, 246; Hess, v. Graefe's Archiv, XL, 1, 1894, 274; MacDougall, Mind, XI, 1902, 316; XII, 1903, 289; C. E. Ferree, this *Journal*, XVII, 1906, 79-121.

[2] Pogg. Ann., XLIV, 1838, 221, 513; XLV, 1838, 227; L, 1840, 193, 427. The theory was conceived earlier by Scherffer (Abhandlung von den zufälligen Farben, Wien, 1765; also Journal de Physique de Rozier, XXVI, 175, 273), who explained the negative after-image by the diminished sensitivity of the fatigued retina.

[3] Müller's Archiv f. Anat. u. Physiol., 1852, 461; Pogg. Ann., LXXXVII, 45; Philos. Mag., (4) IV, 519; Physiol. Optik, 1896.

[4] Ann. de Chimie et de Phys., LIII, 1833, 386; LVII, 1835, 337; Pogg. Ann., XXXII, 1834, 543. More fully in Essai d'une théorie générale, etc., Mem. de l'Acad. de Belgique, VIII, 1834. For a still earlier form of the theory, see de Godart, Journal de Physique de Rozier, VIII, 1776, 1, 269.

[5] Zur Lehre vom Lichtsinne, 1874; v. Graefe's Archiv, XXXVII, 3, 1891, 1; XXXVIII, 2, 1892, 252.

[6] Zur Psychophysik der Gesichtsempfindungen, 1897 (off-printed from Zeitschrift f. Psychologie, X, 1896, 1, 321; XIV, 1897, 1, 161).

The oscillatory theory, in general, does not attribute to eye-movement any direct influence upon adaptation. As formulated by Plateau, 1833-35, it was primarily intended to explain the occurrence of the positive and negative after-images, the fluctuation of the negative after-image, and the flight of colors. Every light stimulation arouses two processes in the retina: the one corresponding to the positive visual impression, and the other to the negative after-image. When the eye has been stimulated by light and the stimulus is removed, the retina attains to its normal state only after a series of oscillations between these opposing processes. When the after-effect of stimulation is observed in an illuminated field of vision, the positive phases of the oscillating processes are obscured by the general illumination. Hence we have the phenomenon of the negative after-image and its fluctuation (the phases of invisibility of the negative after-image corresponding to the recurrence of the obscured positive after-image). When, however, the observation is made in a darkened field of vision, all the changes are noticeable. The changes thus observed in after-images of certain brightly luminous stimuli have been denominated the 'flight of colors.'

The phenomenon of adaptation was not discussed in this early form of the theory. It was taken into account only when the cardinal features of Plateau's theory (the antagonistic nature of the visual processes and the oscillatory after-effect of stimulation) were later made the basis of a group of visual theories, of which the Hering theory may be taken as the type. These theories were called upon to explain not only how the eye becomes adapted to a given stimulus, but also how, when once adapted, it is restored to its normal state. In general, they account for the restoration of the adapted retina by the conception of antagonistic processes; every visual process carries with it its corrective process. All factors extrinsic to the processes themselves are declared to be unimportant. It is said, *e. g.*, that the eye does not become permanently adapted to a given set of stimuli, or condition of illumination, first, because of the tendency toward correction inhering in the nature of the opposing processes, and, secondly, because the stimulation of the eye is continually changing, owing to changes in position of body and head, movement of eyes, blinking, etc. But these latter factors are on no account to be considered as exerting a direct influence on the retinal processes. They merely give the corrective tendency, inhering in the sets of processes, a better chance to operate.

It will be seen that the above mentioned provision explains the relief of adaptation only in a general way, and also inadequately. For, without taking into consideration extrinsic in-

fluences, it cannot account for the comparatively large measure of restoration brought about in the short intervals of relief from stimulation afforded by the involuntary eye-movements which occur under the conditions of normal fixation, or by voluntary eye-movements, of short duration, away from the stimulus and back again. The intervals are much too short for correction to take place, to such a degree, of its own accord.

As these disturbances in adaptation cannot be explained, they are denied to be of any considerable importance. Involuntary eye-movement under the conditions of normal fixation, or voluntary eye-movement away from the stimulus and back again, is said to exert no noticeable effect upon the restoration of the adapting stimulus, or upon its obverse aspect, the negative after-image.[1] The interval, during which the retina is shifted away from a given stimulus, must in point of time alone account for the progress it has made towards regaining its normal condition.

On the other side, however, the representatives of the theory of fatigue attribute a direct influence to eye-movement in restoring the stimulated retina to its normal state. This influence is inferred, more particularly, from the effect of eye-movement upon the negative after-image. The argument is as follows. A voluntary eye-movement, or a noticeable involuntary eye-movement, causes the after-image momentarily to disappear. The negative after-image may be taken as the index of retinal fatigue; hence whatever is able thus profoundly to disturb the cause of the after-image must also function in the recovery of the fatigued retina.[2]

According to Fechner (*opp. citt.*) eye-movement causes the after-image to disappear because of mechanical disturbances in vascular and nervous influences on the retina: temporary vascular congestion, etc. Helmholtz[3] says that eye-movement causes the after-image to disappear by producing changes in the illumination of the retina. Both writers, apparently, have practically disregarded the effect of eye-movement upon the total duration of the after-image; although, as will be shown later, this must be considered a much more important factor in a study of the restoration of the adapted retina than are the momentary disappearances or fluctuations of the after-image.

Of the more recent writers, Fick and Gürber contend that eye-movement changes the lymph-stream in a way that facilitates the removal of the fatigue products and the delivery of

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[1] Hering: *opp. citt.*

[2] See especially Fick and Gürber, v. Graefe's Archiv, XXXVI, 2, 1890, 246.

[3] Physiol. Optik, 1896, 510.

new material to the fatigued areas. Hering,[1] replying to Fick and Gürber, denies to eye-movement any peculiar power to relieve adaptation. He asserts that movement of the field of vision, for example, answers the purpose equally well. Hess (*op. cit.*) contends that an adapted stimulus, steadily fixated, is not recovered, but does not explain how eye-movement restores the adapted retina. Finally, MacDougall (*opp. citt.*) explains the effect of eye-movement upon the reappearance of minimal visual stimuli on the basis of innervation.

This is the condition in which we find the problem at the present time. The oscillatory theory makes no provision for any noticeable effect of eye-movement upon adaptation, nor can it explain the after-image results which we ourselves have obtained. Fechner and Helmholtz ascribe to eye-movement a direct influence upon adaptation, but their hypothesis as to the way in which this effect is produced can be shown to be untenable. MacDougall's position has already been discussed by the writer;[2] while Hering, as will be shown later, did not carry his observations far enough.[3]

While, however, the literature does not furnish a satisfactory solution of the problem, it strongly suggests a method of investigation. It is evident that we cannot adequately study recovery while the stimulus is acting. We can only note the coincidence of eye-movement, or what not, with recovery. What goes on, in the small interval for recovery afforded by a single eye-movement, defies observation or experimental analysis. Fortunately, however, the after-effect of stimulation affords an easy and obvious point of attack. Here we can study recovery in isolation, and may hope to determine the factors that influence it: the factors that cause the fluctuations and affect the duration of the after-image. In accordance with this plan, a series of experiments on the negative after-image was begun in the Cornell University laboratory in the spring of 1904. The results of these experiments will form the subject-matter of this and the following papers.

The material may be classified under the following heads: I. Relation of the negative after-image to adaptation; II. Fluctuation of the negative after-image; III. Duration and fluctuation of the negative after-image with reference to its bearing upon the intermittence of minimal visual stimuli. This, the logical order of treatment will, however, be changed for the sake of convenience of discussion. The determination

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[1] v. Graefe's Archiv, XXXVII, 3, 1891, 22.

[2] This *Journal*, XVII, 1906, 89.

[3] Fick and Gürber's hypothesis, although too indefinite and too speculative, seems to be the most promising of any of the historical hypotheses. It will be discussed later.

of the relation of the negative after-image to adaptation depends, in part, upon the results of the two succeeding inquiries, and can therefore be most conveniently taken up at the end of the series. We shall, accordingly, begin with a discussion of the cause of the fluctuation of the after-image, and of the factors influencing its duration. In terms of theory, these must constitute the factors that work for the restoration of the stimlated retina; for whatever theory is held of the adaptation and after-image phenomenon,—whether it be ascribed to fatigue, to antagonism of retinal processes, or what not,—the factors that work against the after-image operate to restore the stimulated retina to its normal condition. To make our position more secure, however, we shall report, in a second paper, adaptation experiments which show that the experimental variations that increase the frequency of fluctuation of the after-image and decrease its duration increase the time required for a stimulus to adapt; and, conversely, that the devices that decrease the frequency of fluctuation and increase the duration of the after-image increase the time required for a stimulus to adapt. The tests thus established will then be applied to the fluctuation of liminal stimuli. It will be shown that whatever increases the fluctuation of the after-image and decreases its duration, increases the phase of visibility and decreases the phase of invisibility of the liminal stimulus; and conversely, that whatever decreases the fluctuation of the after-image and increases its duration, decreases the phase of visibility and increases the phase of invisibility of the liminal stimulus; as should be the case, if the fluctuation of liminal stimuli is an adaptation phenomenon.[1] Thus the chain of identification will be rendered complete. The intermittence of minimal visual stimuli will have been made to answer to the tests for adaptation, from both its obverse and its reverse sides. Moreover, in the progress of the work. an answer will be found to the question how eye-movement is able to relieve adaptation.

The whole course of the work which we have undertaken on the fluctuation of minimal visual stimuli may be summarized as follows. First, an examination of the phenomenon was made for the ascertainment of its possible causal factors. These were found to be disturbances in accommodation; adaptation, which is found to be intermittent with normal fixation; fluctuation of attention; and physiological disturbances in the visual centre due to the function of other brain centres, such, for

[1] This result follows directly from the adaptation experiments just referred to. For whatever increases the fluctuation and decreases the duration of the negative after-image, increases the time required for a given stimulus to adapt (the phase of visibility when the stimulus is liminal), and so on.

example, as the respiratory and circulatory centres. Secondly, we eliminated, by experimental process, all of these factors with the exception of adaptation. Thirdly, we have been able to identify fluctuation with intermittent adaptation from both its obverse and its reverse sides. And fourthly, we have determined the factors that disturb adaptation.

II. The Fluctuation of the Negative After-Image.

There is a strong interest in the fluctuation of the negative after-image, independently of its bearing upon our special problem. It is generally recognized as one of the important problems in psychological optics, and one not as yet adequately taken into account by visual theories. We find, for example, Plateau, Aubert, Hering, Ebbinghaus and others holding that periodicity is grounded in the nature of the after-image process; the followers of Fechner and Helmholtz contending for accidental influences of various kinds which operate upon the fatigued retina; and Exner maintaining that eye-movement causes the after-image to disappear, because it distracts from clear perception. The question, then, is still open. The evidence is such that, unless prejudiced in favor of some particular explanation, one cannot subscribe to any without further investigation. Thus, von Kries, writing in 1905, testifies to the lack of decisive results as follows: "Die Frage, ob das Schwinden einer lokalen Umstimmung sich überhaupt in dieser Form eines allmählichen Abklingens vollziehe, ist (ohne messende Versuche) viel diskutiert und mehrfach in verschiedenem Sinne beantwortet worden." [1]

i. *Hering and Exner.*

In our consideration of the various theories, those which deny causal relation between eye-movement and fluctuation, Hering's and Exner's, will be examined first. The hypotheses which seek to explain the effect of eye-movement on fluctuation, Fechner's, Helmholtz' and Fick and Gürber's, will be deferred until a later point in the inqniry. It is convenient to begin with Hering.

a. Hering's discussion of the effect of eye-movement on the fluctuation of the negative after-image (1891) grew out of a controversy regarding the effect of eye-movement upon the restoration of the fatigued retina to its normal condition. In this discussion, he has not kept the two subjects formally separated, so that there must be more or less cross-reference between them in our review; although the centre of interest for us, at this stage, is the fluctuation of the negative after-image.

[1] Nagel: Handbuch d. Physiol. des Menschen, III, 216.

The whole question of the influence of eye-movement on the visual processes was raised by the representatives of the theory of fatigue. They sought to explain first why the eye, fatigued by a particular stimulus, recovers as quickly as it does; and, secondly, why it does not become progressively fatigued by light stimulation in general during the twelve hours or more of its exposure to light in the course of a day. The explanation was given chiefly in terms of the changes brought about in the fatigued retina by eye-movement. As has been stated above (p. 62), Fechner asserted that these changes are of the nature of mechanical disturbances in vascular and nervous influences; while Helmholtz attributed them to the more or less continual changes in the illumination of the retina due to eye-movement in connection with blinking, frowning, etc. Obviously, neither hypothesis is adequate to explain the facts in question.

Fick and Gürber (1890), taking up the problem at this point, were concerned first to furnish a more extended experimental demonstration of the fact that eye-movement is effective to relieve the fatigued retina; and secondly to explain, more adequately than had been done by Fechner and Helmholtz, how this relief is accomplished. The first point will not be discussed here. The explanation may be summarized as follows: eye-movement restores the fatigued retina by influencing the metabolic changes that take place in the fatigued area; it both facilitates the removal of the fatigue products from this area, and augments the delivery of new nutrient material to it.

Replying to Fick and Gürber, Hering denies that eye-movement affects the visual processes, and explains the absence of progressive fatigue by his conception of assimilative and dissimilative processes which are mutually corrective. He bases his denial that eye-movement is a factor in restoring the stimulated retina to its normal condition upon four experimental proofs, all adduced to show that it neither causes the negative after-image to disappear nor produces any other noticeable disturbance in its temporal course. These four proofs are as follows. (1) After continued fixation of a stimulus, the after-image does not disappear when the eyes are rapidly moved away from the stimulus and back again. (2) Movement of the background causes the after-image to disappear; hence eye-movement can possess no peculiar power to produce its disappearance. (3) Near-lying after-images due to successive stimulations do not fluctuate together. (4) Eye-movement does not cause the after-image to disappear, when it is observed in a darkened field of vision. These points will be taken up in the order given.

(1) The demonstration is as follows. If a disc or square of

dead black paper is laid on a white background, and its centre fixated for some time; and if the observer then moves his eyes quickly out to some near-lying point and back again to the neighborhood of the stimulus; the after-image is not found to have disappeared as a result of the movement.

Hering does not draw any specific conclusions from this experiment alone. It will be remembered, however, that by means of it and of the succeeding experiments he wishes to establish the thesis that eye-movement does not cause the disappearance of after-images, or otherwise noticeably interfere with their temporal course, and that it does not factor in the restoration of the fatigued retina. It seems fair to add, as an obvious corollary to this thesis, that it does not cause the fluctuation of the negative after-image. Now it is evident that the experiment is of little or no value in the present connection. (*a*) For to conclude from it that eye-movement does not cause after-images to disappear would be to generalize from a very special case, namely, from an after-image of high intensity. The result is very different when the after-image is weaker; eye-movement readily brings less intensive after-images to disappearance. In general, after-images obtained with so long or even with a less long period of stimulation must dim to some extent (the amount depending upon the time of stimulation) before eye-movement can cause them to disappear. (*b*) To conclude from it that eye-movement does not factor in the restoration of the fatigued retina to its normal condition would be to apply a test that is over-strict. It is not necessary that the after-image disappear. A dimming of the after-image should indicate partial restoration of the fatigued retina. In fact, the writer has shown in the rough, by a series of experiments to be described in a later paper, that the restoration of the adapted retina is proportional to the loss of intensity in the after-image. The disappearance of the after-image corresponds to complete restoration of the adapted retina, and should not be required as evidence that partial restoration has taken place. To demonstrate, then, that eye-movement factors in the restoration of the retina, it need be shown only that the after-image has lost in intensity; and proof of this is easy, however strong the stimulation. Observations made with reasonable care give the uniform result that after-images, of whatever intensity, are dimmed by eye-movement. (*c*) To conclude from it that eye-movement is not a causal factor in fluctuation would be to ignore certain relevant facts. After-images of such intensity do not fluctuate. Just as they must dim, to some degree, before voluntary eye-movement can cause their disappearance, so must they dim before fluctuation begins. If, therefore, the argument from

analogy is to be used at all, the investigator must first determine at what intensity after-images begin naturally to fluctuate, and at what intensity voluntary eye-movement of a suitable range begins to cause disappearance; and may then ask whether a rough correspondence obtains between the two points. This procedure was followed by the writer with a number of observers; and the results show, uniformly, an exceedingly close correspondence. A description of the method used and a statement of the results are given further on, p. 103 ff. Obviously, then, nothing can be derived from this experiment that will aid in demonstrating either the Hering thesis or its corollary.

(2) In his second observation, Hering is concerned to disprove Fick and Gürber's theory that eye-movement facilitates metabolic change in the retina. Even if disappearance does follow movement of the eyes, he says, it is not necessarily implied that eye-movement possesses any peculiar power to cause disappearance; for movement of the background yields the same result. The effect of moving the background is explained as follows: "Dies hat seinen Grund in der Wechselwirkung der Sehfeldstellen und zum Theile auch darin, dass die Augenmedien nicht ganz homogen sind und daher immer mehr oder weniger Licht von der Bahn abirrt, die wir ihm theoretisch zuschreiben." The explanation would seem to give up the whole controversy; for, as it stands, precisely the same effect should be produced by moving the eyes as by moving the background. However, we let this point pass, and proceed to consider the statement that movement of the background causes disappearance. That is true. It is possible, within limits, to duplicate, by movement of the background, any fluctuation series that may be produced by voluntary eye-movement. In all such cases, however, the eye is tempted to movement by the moving background. At any rate, when the eye is held steady, movement of the background does *not* cause the after-image to disappear. This may be demonstrated as follows. (*a*) Use for the background the mottled surface presented by the darker side of engine-gray cardboard. Project the after-image. Let it become sufficiently dim, and move the cardboard in any direction. Disappearance takes place. Now, place a fixation point immediately in front of the background; *e. g.*, a black knot in a taut vertical white cord. Fixate this steadily. Movement of the background scarcely dims the after-image. (*b*) The following method is probably not so fair a test of Hering's position as that just described, since he asserts that a change in the illumination of any part of the retina acts reciprocally on other parts. Hence the maximal effect would be produced, we may suppose, by movement of the whole background, and not by movement of the particular area

upon which the after-image is projected. However, the facts may speak for themselves. Use the same mottled engine-gray cardboard for the background. Place just in front of it a sheet of same kind of cardboard, with a hole of the exact size and shape of the after-image to be observed. Looking through this hole, project the after-image upon the background. Move this in any direction. Now that the major portion of the field of vision is steady. the shifting of the area upon which the after-image is projected does not noticeably disturb fixation, and correspondingly does not cause the after-image to disappear. (Instead of a sheet of cardboard, a disc mounted upon a color-mixer may be placed behind the opening. When the after-image is projected upon it, the disc may be rotated at any chosen rate of speed without sensibly dimming the image.)

(3) Hering's third demonstration is as follows. Place a short, broad strip of colored or dark paper on a white background 5 mm. to the left of a fixation point. Observe for 10 sec. Quickly remove it and place a similar strip, parallel to the position of the first, 5 mm. to the right of the fixation point. Observe for 10 sec. Remove this, and replace the first strip for 10 sec. Then remove the first, and replace the second strip for 10 sec. Thus the eyes have been exposed to both strips for 20 sec., with an intermission for each of 10 sec. The object of this arrangement was, apparently, twofold: first, by successive stimulation, to start the after-images in different phases of oscillation, and thus to cause them to fluctuate successively; and secondly, by causing them to fluctuate successively, to show that eye-movement cannot have been responsible for their fluctuation, but rather that oscillation is grounded in the nature of the visual processes. With regard to the first point, however, it can be shown that there is no especial virtue in successive stimulation to produce successive fluctuation in after-images situated on different parts of the retina. If two stimuli, not too large, are placed at a certain distance apart and allowed to act simultaneously, their after-images rarely fluctuate together. This is one of the common phenomena of fluctuation, whatever the temporal character of the stimulation, and it is in nowise essentially dependent upon successive stimulations. With regard to the second point,—that if eye-movement had anything to do with the fluctuations, the after-images should have fluctuated together, and not independently of each other,—we urge that the conclusion does not by any means follow from the premisses. It is true, as is pointed out by Hering, that both areas of the retina had been stimulated for the same length of time; and that, so far, the after-images should have been affected alike by eye-movement. But Hering overlooks the fact that the one after-image had been fading for 10 sec.

before the stimulus to the other was removed. It had thus run a large part of its course before the other began, and hence might be expected to disappear under a range of movement that would scarcely dim the other. We cannot only say that eye-movement may have been the cause of the independent fluctuation, but we can go farther and say that the after-images behaved precisely as they should have done if eye-movement were the cause of their fluctuation.

But farther, Hering's result, as well as his conclusion, must be called in question. The writer has tried the experiment upon himself and a number of observers, and so far from finding Hering's results invariable or even typical, has rarely met with a case in which, after the first couple of fluctuations, the one strip disappeared as a whole while the other remained intact. Instead of that, the whole area formed by the two broad strips and the narrow contrast strip between fluctuated, either as a whole or in parts, as all after-images of a certain magnitude do. When the fluctuation was in parts, now a corner of the area would drop away, now a strip across the top, now an irregular patch here followed by an irregular patch there, etc., etc. When the area fluctuated as a whole, first the two outside strips would spread over the intermediate space, the whole area becoming dim in consequence; then the entire image would disappear. When observation was made on the closed lids, this experiment furnished an excellent demonstration of the relation of the 'streaming phenomenon' to fluctuation.[1]

Hering's arrangement failed to give successive fluctuation for the reason that the strips were too large for their distance apart. In this zone of the retina, the zone of fluctuation in parts, the area included in each disappearance was not large enough to include the whole strip. Had the strips been placed farther apart, or made smaller and placed as Hering directed, the successive fluctuations aimed at would have been uniformly obtained; but their occurrence it is plain, would in no wise have demonstrated the intrinsically oscillatory character of the underlying visual processes. Still better results, however, would have been obtained if the stimuli had been smaller and also placed farther apart. A square or rectangular after-image, large enough to include the strip-areas, would also have fluctuated successively in parts, the fluctuating area now and then corresponding to, or including, the two strip-areas, in turn. All these fluctuation phenomena are due to variation in the

[1] For a description of this phenomenon, see below, p. 114, and for an explanation of its relation to the after-image, p. 123. The stream could be plainly seen to diffuse the color or gray of the two outside strips over the intermediate strip, and finally to blot out the whole image.

area of the retina involved, and have nothing to do with successive stimulation. Over a certain range of areas, fluctuation in parts is the invariable occurrence, whatever the temporal character of the stimulation.

We may now sum up the discussion of this experiment. So far from showing by his special device of successive stimulations that eye-movement cannot be the cause of fluctuation, and so far from throwing any difficulty in the way of the eye-movement hypotheses, Hering has succeeded rather in making it easier to explain, by eye-movement, the results which he obtained. In other words, he has produced the phenomenon of fluctuation in parts in the only way, known to the writer, in which it admits of ready explanation by the theories of Fechner, Helmholtz, and Fick and Gürber. In terms of any eye-movement hypothesis, the difference in intensity of the two after-images is amply sufficient to explain why a given eye-movement should not affect both of them alike. Hering's results would have been more difficult to explain had he used simultaneous stimulation. It is much more difficult, *e. g.*, to say in terms of eye-movement why after-images of a certain area fluctuate in parts, or why small after-images due to simultaneous stimulation of different parts of the retina fluctuate independently of one another. The fluctuation in the case both of simultaneous and of successive stimulation is, however, of the same nature, and its cause must, evidently, be assigned upon other grounds than those here given by Hering.

(4) As a final step in his argument, Hering maintains that, in order to a final decision of the question whether eye-movement exerts any influence upon the disappearance of the after-image other than by causing changes in the illumination of the retina, the course of the after-image must be traced in a darkened field of vision. He maintains that under these conditions eye-movement does not noticeably alter the natural course of the after-image, much less cause it to disappear. A few sentences further on, however, he qualifies this statement by the remark that, when observing in a dark-room, he was never able entirely to blot out an after-image that was at all distinct or intensive, by moving the eyes.[1]

[1] "In den ersten Paragraphen meiner Mittheilungen zur Lehre vom Lichtsinne habe ich eine Reihe von Erscheinungen besprochen, welche man an Nachbildern im geschlossenen und verdunkelten Auge beobachtet. Ich hatte bei solchen Versuchen reiche Gelegenheit festzustellen, dass Augenbewegungen den gesetzmässigen Verlauf dieser Nachbilder gar nicht merklich beeinflussen. Auch habe ich zahlreiche Versuche in einem Zimmer angestellt, welches völlstandig verdunkelt werden konnte, nachdem ich mir das Nachbild erzeugt hatte. Hier hatte ich den Vortheil, die Augenbewegungen bei ebenfalls offenen Augen ausführen zu können. Nie war es möglich ein irgend

Apparently, there is here a tacit admission that eye-movement causes weaker or less distinct after-images to disappear. If so, the argument against it as a causal factor is materially weakened; for, as has been stated earlier in the discussion, intensive after-images do not fluctuate at all. They must become sufficiently dim if fluctuation is to set in. In any event, however, observation is the court of final appeal. We must determine, first, whether eye-movement does cause after-images, weak or strong, to disappear when they are observed in a darkened field of vision; and secondly, whether the point at which fluctuation begins roughly coincides with the point at which eye-movement first causes the after-image to disappear. A series of experiments was conducted to this end. Many stimuli were used, colored and gray, and the after-images were observed under the following conditions: with the eyes closed and carefully covered by a black cloth; in the dark-room, with the eyes both open and closed; and in the blackness cylinder. In every case eye-movement caused disappearance when the after-image had become sufficiently dim, and this point roughly corresponded with the point at which fluctuation began. The following results, which are typical, have been selected for publication. In this case the stimulus was a square of Hering white paper, 5 by 5 cm., on a background of Hering gray no. 31; and the after-image was observed with the eyes closed and covered with a black cloth. Miss Alden, a graduate student in psychology in the University of Colorado, acted as observer. The time of stimulation was 40 sec., and the distance of the observer from the stimulus was 75 cm. The recording apparatus consisted of kymograph, telegraph key and electro-magnetic recorder, and electro-magnetic time-marker in circuit with a small chronometer set to half-seconds. When the disappearances were caused by eye-movement, the eyes were moved every 3 sec., at a signal from the experimenter. It may be well to add that the results showing the closest approximation have not been chosen for publication. In the case selected, too much eye-movement was prescribed. The after-image began to fluctuate at a greater intensity than in the companion series of natural fluctuations. There were more frequent fluctuations, and the average phase of visibility was shorter. Erring as they do, however, on the side of making eye-movement too effective, these results tell more strongly against Hering's assertion that eye-movement does not cause disappearance in a darkened field of vision than do the results

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deutliche Nachbild durch Augenbewegungen, auch wenn sie ungewöhnlich gross und lebhaft waren, zum verschwinden zu bringen." In v. Graefe's Archiv, XXXVII, 2, 1891, 23.—*Cf.* also S. Exner, Zeits. f. Psychol., I, 1890, 47.

which show a closer approximation. For this reason, and also because about the same amount of eye-movement was prescribed as in the other duplication experiments which had already been carried out, this particular series has been selected.

TABLE I

A. Showing results for a darkened field of vision when the fluctuations were natural, and when they were produced by voluntary eye-movement. Unit 1 sec.

TYPE OF FLUCTUATION	NO. OF FLUCT'S	1st VIS.	AV. VIS.	TOTAL VIS.	AV. INVIS.	TOTAL INVIS.	VIS. + INVIS.
Natural	7	9.9	6.6	46.2	2.2	15.4	61.6
Produced by Voluntary Eye-movement	8	6.2	4.8	38.4	2.5	20.0	58.4

With regard to the natural fluctuation of after-images, when observed in a darkened field of vision, Hering says: "An den ersterwähnten Nachbildern (*i. e.*, those due to a bright object seen on a dark ground, fixated for 10-30 sec.) aber erfordert es sogar besondere Aufmerksamkeit wahrzunehmen, dass das negative Nachbild nach längerem Bestehen nicht bloss vorübergehend verschwindet, sondern dass sich zwischen sein Verschwinden und eventuelles Wiedererscheinen eine schwache positive Phase einschiebt, die freilich oft genug überhaupt nicht merklich wird."[1] It is difficult to determine whether this statement means that the weak positive phase occupies all of what usually passes for the phase of disappearance, or only a part of it. If it occupies the whole time, there is of course no intermission in the after-image process. The disappearance usually observed is merely an artifact, produced by observation with the retina illuminated. In view of this uncertainty it seemed worth while to repeat the experiments. Hering says that the recurrence of the positive phase may be observed if one fixates a bright object on a dark ground for 10, 20, or 30 sec., and then watches the after-image in a darkened field of vision. A square of white paper on a dark ground was taken as stimulus. This gave, as negative after-effect, a black square with a distinct contrast border of brilliant white on a very light gray ground. The black square fluctuated frequently; but there was never left in its place, nor did there ever appear anything that resembled, a square of white or light gray. When it disappeared, however, some part of the contrast border at times remained momentarily visible and often could be seen to

[1] *Op. cit.*, 18.

reappear slightly in advance of the black square;[1] but this phenomenon could scarcely be mistaken for a weak phase of the positive after-image. A small, irregular patch of slightly luminous haze is also frequently noticed about the point of regard.[2] But this occurs just as frequently during a phase of invisibility when the eye has been exposed to a colored or white stimulus, or in the darkened field of vision when the retina has undergone no local stimulation at all; hence it cannot be a positive after-effect of stimulation.

In order to make the test-conditions still more favorable to Hering, we substituted for the dark gray background prescribed by him a light gray (Hering no. 15). Under the original conditions, the positive phase must have been difficult to distinguish, had it occurred. The negative after-effect now obtained was a black square upon a ground of gray such that not only would the lighter positive phase have been easily distinguishable, if it occurred, but that it would also have been considerably intensified by contrast. Still the positive phase could not be detected during the periods of invisibility of the negative phase.

When the stimulus is luminous, Hering says that the positive phases are plainly present, alternating with the negative. As before, two experiments were made upon this point by our observers: the one with the background light, but not so bright as the stimulus; and the other with the background dark. In the first experiment, the sun's disc and Colorado daylight served as stimulus and background. The bright background intensified the darkened field of vision in the after-effect, and thus, as far as brightness was concerned, favored by contrast the observation of the positive phase of the after-image. The eye was stimulated, probably, from 1 to 3 sec. The observations were made in mid summer, near the middle of the day. The sky was cloudless, and the light very intensive. While, now, it is difficult to decide what is positive, and what negative, in the color changes that follow exposure to a brightly

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[1]This, of course, is merely an instance of fluctuation in parts. The area that was swept out by the stream, or complex of streams, did not at first include this particular part of the contrast border; but soon, owing to the spread of the area of commotion, the contrast border became involved in the disappearance. The reappearance of a part of the border in advance of the remainder of the after-image is a phenomenon of the reverse order. The border was cleared of the streaming material before the rest of the image.

[2]Close observation shows this to be a centre of activity of a 'streaming' area. It also occurs, but less noticeably, in other parts of the field of vision more remote from the point of regard. Such patches are usually found to be the foci or places of intersection of narrow, swiftly moving streams.

luminous stimulus, still our observers reported, here as in the former experiments, unquestionable, well defined phases of disappearance. Voluntary eye-movement also produced disappearance when the after-image had reached the dimness at which fluctuation begins.

When exposed to the sun's disc, the eye was purposely moved in order that the after-image might be jagged and irregular. This was of some advantage for observation, because the limbs of the after-image, owing to their less intensive stimulation, passed through the color changes slightly in advance of the body. The after-image was observed with the eyes closed and covered with a black cloth. The following report is typical:

There was first a momentary lasting over of the stimulus in the body of the after-image, while the edges were a deep red. The body then changed to a light blue. The red border, in the meantime, had been gradually extending inwards, especially in the limbs of the image.[1] The edges of the central blue patch next began to change to a yellow-green. While this change was going on, the outer margin of deep red was encroaching, more and more, upon the centre. When the central portion had become almost entirely yellow-green, the marginal red had taken on a border of deep blue.[2] All the central portion next became yellow-green. The red border encroached still farther upon the centre, and was in turn encroached upon by its border of dark blue. The centre then showed a tendency to become light blue again. Finally, the whole image became a deep red with a dark blue margin. This stage lasted for a comparatively long time, and disappearances were frequent. Next, the dark blue of the margin spread gradually over the entire image. There were later a few faint recoveries (following disappearances) of a lighter blue; then came in order a light red-violet, a violet-blue, and a dull dark yellow. In these last fainter stages complete disappearances were especially frequent.

The fluctuations observed in this experiment were not different from those occurring under the usual conditions. The

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[1] At this stage, there was a very noticeable effect of perspective. The red seemed to be projected farther into the background than the blue, farther back even than the general field of vision, as if it were sunk or seared into the field. The blue seemed a detached and floating patch, which was now and then swept away by a stream, changing its shape as it went, and dissolving in the stream body.

[2] These changes were not all gradual or continuous. Sometimes the central patch would change from light blue to the next stage, yellow-green, and back again; at times it would go from blue to the deep red, and back to blue again; and sometimes it would disappear entirely, frequently repeating in its reappearance all the color stages in their inverse order. Sometimes it would come back suddenly to the color from which it fluctuated; and, very occasionally, the order would be irregular. These changes were always connected with the streaming phenomenon. Light streaming, apparently, caused the changes from color to color, while heavy streaming blotted out the image entirely. Recovery came with the clearing away of the streaming material.

after-image fluctuated as a whole, and in parts, as all after-images do. Now one of the limbs would drop off; now the lower part, now the upper; now the image would disappear across the centre; and again it would disappear completely. In fact, this experiment, so far from furnishing evidence against fluctuation, gives (owing to the long duration of the after-image) an unusually good demonstration of the various phenomena that characterize fluctuation.

Experiments were also made with a dark background. Here, as before, observation showed clearly marked periods of disappearance. The intermission was absolutc. No part of the interval was occupied by anything that could be identified with a recurrence of the positive phase at low intensity. Further details appear needless, as the conditions already described were more favorable than those of the dark ground for the observation in question.

It is logically impossible, then, to conclude from the foregoing experiments, as Hering does, that eye-movement is ineffective in the disappearance of the after-image, or that fluctuation is merely the alternation of negative with weak positive phases of the after-image. It is obvious, rather, that eye-movement is able to cause the diappearance of any after-image that will fluctuate.—

b. Exner argues against the view that intermittence is grounded in the nature of the after-image process. It is a well-known fact, he says, that eye-movement will cause an after-image to disappear. Nor does eye-movement affect the after-image process. The eye, moving in some particular direction, causes the field of vision to travel across the retina in the opposite direction. This moving field of vision, by distracting from the perception of the after-image which is stationary upon the retina, causes it to drop out of clear consciousness. When the eye comes to rest, the distraction is removed, and the after-image reappears.[1] Now, this explanation accounts, at best, only for our inability to see the after-image while the field of

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[1] Exner and Hering thus agree, though from different points of view, that there is no particular virtue in eye-movement to cause the disappearance of the after-image. Movement of the background works just as well. It is worthy of notice, however, that while Hering uses the statement as an argument for the oscillatory theory, Exner uses it as an argument against. Exner thinks it evident that movement of the visual field distracts from the clear perception of the after-image just as it distracts from the clear perception of objects actually in the external visual field; and explains the whole effect of movement of the background in this way. It is an easy step, then, to infer that the disappearances produced by voluntary eye-movement are to be similarly explained, and to refer the fluctuations occurring under the conditions of normal fixation to involuntary eye-movement rather than to oscillation of visual processes.

vision is in motion. It does not account for the invisibility of the image after the eye has come to rest. There are, however, two cases of this inability to see the after-image while the field of vision is in motion. In the one, the after-image is vaguely seen throughout, but cannot be seen clearly so long as the eye is in rapid movement. It comes out at once when the motion lags or ceases. This corresponds to Exner's distraction phenomenon; but it is not what is ordinarily meant by disappearance. The other is a case of true disappearance. The after-image goes out absolutely. It does not reappear as the motion lags, and is still invisible after the eye has accurately regained its fixation. In the writer's experiments upon fluctuations produced by voluntary eye-movement, a disappearance was not recorded unless the after-image remained invisible after the observer had accurately regained his fixation. Disappearances of this sort were evidently not due to distraction, for distraction had ceased before the record began.

Although Exner thus seems to be mistaken in his view of the disappearance produced by eye-movement, his theory will be put to experimental test. A direct corollary from it is that the effect of eye-movement upon the disappearance of the after-image bears an inverse relation to the uniformity of the projection field. There are three sets of conditions under which this relation should obtain: (*a*) disappearance under the conditions of ordinary fixation; (*b*) disappearance produced by voluntary eye-movement; and (*c*) disappearance caused by movement of the background. It certainly does not obtain under the first conditions. The after-image fluctuates with equal readiness when projected upon lettered surfaces, upon mottled engine-gray cardboard, upon either the dull or the glazed surface of milk glass (than which there is probably no more uniform background), and upon the Hering gray papers. Nor does it seem to make any difference which of the above backgrounds is used, when the disappearance is caused by voluntary eye-movement. The inverse relation does, however, seem to hold, within limits, when the disappearances are caused by movement of the background; the mottled backgrounds have, apparently, more effect than the uniform. Now it is evident that the mottled background, travelling across the retina, could distract no more from the perception of the after-image in this case than in the other two. It would, however, in proportion to its irregularity, distract from steady fixation. Thus the difference is to be explained in terms of increased eye-movement; and again the argument against eye-movement, upon more careful investigation, is converted into an argument for some sort of eye-movement hypothesis.

As the matter stands, then, with regard to Hering and Ex-

ner, eye-movement must still be taken into account in the explanation of the fluctuation of the negative after-image.

ii. *Demonstration of causal connection between eye-movement and fluctuation, as against the theory of intrinsic oscillation.*

a. Results in general.—In order that the thread of the argument may not be lost in the tables and details that follow, a brief general statement of results is here given.

(1) *Fluctuation occurs only within a limited range of after-image areas.* It is a matter of common laboratory report that fluctuation does not take place in the after-effect of general adaptation. The after-effect dies away gradually. There are none of the intermittent variations of intensity that characterize the after-effect of local adaptation to stimuli of certain areas. This fact is brought out in practically all the record-books kept by members of the junior training course at Cornell University. Careful tests have also been made, with the same result, by the help of observers trained to work with just noticeable differences, by whom even slight variations in intensity would have been noticed.

We turn to the after-effect of local adaptation. Here we find that fluctuation occurs only within a comparatively limited range of after-image areas, varying somewhat for the different colors used, and for different observers. Large after-images do not fluctuate at all; small after-images little, if at all; after-images of mean area alone fluctuate readily. If a curve of frequency were plotted with the areas laid off along the ordinate and the frequency of fluctuation along the abcissa, the curve would start close to the abcissa, rise gradually until a certain area was reached, and then bend down rather more sharply to the abscissa. This result is, apparently, incompatible with the hypothesis of intrinsic oscillation. Absence of fluctuation for a single area would tell strongly against that theory; and such a range of variation as is expressed in the curve of frequency would seem to condemn it absolutely. The shape of the curve of frequency, together with the fluctuation in parts of after-images of certain areas, is the most difficult problem that the fluctuation of the after-image presents to theory. That eye-movement, acting in co-operation with streaming, offers a satisfactory explanation of all the variations resulting from change in area will be shown in detail in its proper place.

(2) *Whatever renders fixation unsteady increases the frequency of fluctuation and decreases the duration of the after-image.* The converse is also true: whatever aids fixation decreases the frequency of fluctuation and increases the duration of the after-image. Various methods were used to disturb and to control fixation. In every case records of eye-movement were

taken, that showed both the range and frequency of the movements and the total time during which the eyes were in motion. A quantitative comparison could thus be instituted between these movements on the one hand, and the frequency of fluctuation on the other. The results show a high degree of correlation.

(3) *The form of the stimulus affects the frequency of fluctuation.* Experiments were made with squares and with narrow strips of equal area. The latter showed a much greater liability to fluctuation. This result can hardly be explained on the theory of intrinsic oscillation; the oscillatory character of the retinal processes must be sensibly the same within a square as within a narrow oblong area. There is, however, good reason to believe that eye-movement differs in the two cases; for when the strip is observed, the introspective reports of the observers bear witness to a strong conscious tendency to look towards the ends, to see what is happening there. The tendency to increased movement with the strip-images is shown also in the eye-movement records. Eye-movement, then, is a factor in the result. Another and, as we shall see later, a very important factor is the retinal distribution of the zones of streaming.

(4) *The arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.* A strip after-image, placed with its breadth in the plane of the greater range and frequency of eye-movement, fluctuates more frequently and has a shorter duration than in the inverse arrangement. The greater frequency of fluctuation is due to the action of the greater amount of eye-movement upon the lesser dimension of the after-image. The point may be demonstrated as follows. Let the disappearance be produced by voluntary eye-movement. If these movements are in the horizontal plane, disappearance is more frequent when the breadth of the strip is in the horizontal than when it is in the vertical plane. Conversely, if the eye-movements are in the vertical plane, disappearance is more frequent when the breadth of the strip is in the vertical than when it is in the horizontal plane. An explanation will be given in Section iii, *c*. Were a periodicity grounded in the nature of the after-image process, extraneous influences, like the form and arrangement of the stimulus, ought not thus to affect the frequency of fluctuation.

(5) *The results grouped under (1), (3) and (4) can be roughly duplicated if voluntary eye-movement is brought in to cause fluctuation.* In the experiments under this heading, the same squares were used as in (1); the same strips and squares as in (3); and the same strips and arrangements with reference to the direction of greatest eye-movement as in (4). The cor-

respondence in the results of the two series of experiments is extremely high. Here, then, is a strong indication that eye-movement is a causal factor in fluctuation. Another factor, however, is required for the complete explanation of the results. The methods employed in (1) and (3) were especially devised to vary the amount of involuntary eye-movement from observation to observation. Yet their results were approximated by the introduction of voluntary eye-movement, the amount of which was kept constant from one observation to another. Obviously, therefore, a second factor is at work, which is affected by eye-movement, and which in turn acts upon the after-image. A more complete explanation is given later in terms of streaming.

(6) *An increase of the time of stimulation increases the number of fluctuations of the after-image.* The time of stimulation ranged for the different observers from 10 to 100 sec. Increase of the time of stimulation brought with it an increase in the intensity of the after-image, an increase in eye-movement (shown by the records), and an increase in the fluctuation of the after-image. It cannot, of course, be determined off-hand which of the first two variations is the cause of the third. From the evidence already at hand, it seems probable that eye-movement is responsible for the increase of fluctuation. Moreover, there is no obvious reason why a more intensive after-image, on the ground of its intensity alone, should begin to fluctuate sooner (at a greater intensity) or should fluctuate more frequentiy after it does begin,—as happens uniformly under the present conditions. The problem is, however, capable of definite experimental analysis. Increase of intensity can be obtained by a method which does not cause an increase of eye-movement; namely, by increase of the intensity of the stimulus. In this case there is no increase of the number of fluctuations. We thus have new and positive evidence that eye-movement is a causal factor in fluctuation. A long period of fixation increases involuntary eye-movement, and this again increases the frequency of fluctuation, apparently in the same proportion.

(7) *The observers most sensitive to the methods used to distribute fixation showed the widest range of variability of fluctuation and duration.* The observers ranged from very stable to very sensitive. The tables show a variation in results from individual to individual, corresponding to the differences in sensitivity to disturbances of fixation. Thus, B and A were very sensitive, W much less sensitive, and M the least sensitive of all. Correspondingly, B's and A's results are very different for the different variations; W's less, and M's still less different. This correlation, it is clear, furnishes evidence in favor of eye-move-

ment as clear-cut and decisive as that to be drawn from the changes in result produced by the different methods in the case of a single individual.

(8) *Increase of practice in fixation brought with it a decrease in the frequency of fluctuation and an increase in the duration of the after-image.* Towards the close of the semester's work it became clear from the eye-movement records that there was an increased ability to fixate on the part of all the observers. There was also a corresponding decrease in the frequency of fluctuation. The pitch of the curve of frequency for the method of areas, *e. g.*, was lessened. At both ends of the series, areas that had fluctuated earlier would not now fluctuate at all, and areas that formerly fluctuated readily now underwent fewer fluctuations. The effect of practice was especially marked in the case of M. There was also, as the work advanced, a decreased sensitivity to the methods used to disturb fixation. With practice fixation became progressively more stable. A general straightening of the frequency curves, for all the methods employed, was the result.

b. General description of method and apparatus. All methods were ruled out as ineffective that did not produce changes in result markedly greater than the variations occurring from time to time without change of experimental conditions. Experiments were planned in series to be finished at a single sitting. Results obtained at different sittings were never compared directly, nor were the results from broken or interrupted series included in the general averages. The order of presentation of the members of a series was changed from time to time, in order to rule out time and practice errors. Care was taken in the selection of *O*'s to get a random sampling of types both as to visual organization and as to experience. As little as possible was left to the uncontrolled introspection of the *O*'s. The analyses were provided for in the experimental variations, and the *O*'s were asked only for the simplest judgments, and were kept in entire ignorance of the problem and plan of experimentation.

The recording apparatus used throughout consisted of kymograph, telegraph-key and electro-magnetic recorder, with electro-magnetic time-marker regulated by a chronometer set to half-seconds. The experiments were conducted in a long optics room lighted at the one end by two windows reaching from near the floor to the ceiling. The *O*, head in rest, was seated between these windows, so that the light coming from either side and above fell upon the projection-field of engine-gray cardboard 75 cm. in front. The time of stimulation, unless otherwise stated, was 40 sec., and the unit of record was 1 sec.

c. Results in detail. The work was begun three years ago

in the Cornell University laboratory, and continued in the laboratory of the University of Arizona during the year 1905-6; in the laboratory of the University of Colorado during the fall semester of 1906-7; in the Cornell University laboratory during the spring semester of 1906-7; and finished in the laboratory of Bryn Mawr College during the fall semester of 1907-8. The results have been verified both in drill courses and in research, with a wide range of observers of diverse training and experience. The present section of the work was done for the most part in the laboratory of the University of Colorado. A part of it has been repeated in the laboratory of Bryn Mawr College. The following persons served as observers: Professor J. H. Bair (B); the Misses Alden (A), Walter (W), Montgomery (M) and Wright (Wr), students in his laboratory; and Miss Stout (S), a student in the laboratory of Bryn Mawr College.

In the tables account is taken of the following points: the number of fluctuations, the first phase of visibility, the average of the phases of visibility, the sum of the phases of visibility, the average of the phases of invisibility, the sum of the phases of invisibility, and the sum of the phases of visibility and invisibility. One less than the number of phases of visibility has been taken as the number of fluctuations. The last disappearance has not been counted in estimating the number of fluctuations. This number is of value to us as a measure of the disturbance in the after-image process. A still better measure, however, is the frequency of fluctuation, expressed by the average of the phases of visibility. The length of the first phase of visibility is of importance as indicating at what intensity the after-image begins to fluctuate. In general, the stronger the operation of disturbing factors, the greater should be the intensity at which the after-image begins to fluctuate. Accordingly, then, we should expect an increase of eye-movement to decrease the first phase of visibility, and a decrease of eye-movement to increase it.

The conventional use of the term duration has been departed from in this discussion. By duration is here meant the sum of the phases of visibility. This use of the term is in the first place strictly accurate, so far as we have any immediate presentation to consciousness of the after-image process; and, so considered, it has, in the second place, more direct bearing upon the problem of the restoration of the adapted stimulus.

No especial significance is attributed to the phases of invisibility. They are included in the tables merely that a complete account of the temporal course of the after-image may be given.

(1) *Fluctuation occurs only within a limited range of areas.*

This statement holds of all the colors used: Hering standard red, green, blue and yellow. The result varied somewhat, however, for the different colors. The red after-image showed itself throughout to be the most instable. It fluctuated most frequently, had the shortest duration, and was most affected by the various disturbances. At the other extreme was the yellow after-image. It proved the most stable of all. For this reason, since space does not permit of giving results from all the stimuli, the yellow image derived from Hering blue as stimulus has been selected for the following tables; it affords the most rigid test of the effect of eye-movement on the temporal course of the after-image in general.

Areas ranging from .5 by .5 cm. to 61 by 50 cm. (the latter being the dimensions of a single sheet of Hering paper) and viewed at a distance of 75 cm. were employed. A still larger area was required for some observers, if no fluctuation was to ensue. This increase in size was obtained by moving the stimulus nearer to the observer.

It will be noticed from the tables that, with small areas, little or no fluctuation occurs. Then there is increase up to a certain point, namely, 10-20 cm. square, when decrease begins. Fluctuation disappears entirely in the neighborhood of 60-65 cm. square.

If we ask how far eye-movement is to be regarded as a causal factor in the increased fluctuation from small to medium areas, and its consequent decrease, we find the following evidence. Over the range of areas showing increase of fluctuation the observers spoke of a strong conscious tendency to look away from the fixation point in order to see what was happening towards the margins. This tendency constituted a distracting factor for fixation. With small areas, the whole after-image lay within the field of direct observation; consequently there was nothing to distract fixation. With the next set of areas, the edges passed into the field of indirect observation, but were still noticeable. Hence they disturbed fixation in various ways. In the first place, they broke the uniformity of the field of vision; and in the second place the observer was instructed to register only total disappearances, disappearances over the whole area. The margins were not clearly visible, and so tempted the eyes to a readjustment which would bring them into the field of clear vision, and thus make observation easier. With the third set of areas, the margins had passed so far from the field of direct observation as to be of little concern to the observer. The field was of an uniform color and brightness, and the margins did not compel attention.

The eye-movement records confirm these introspections. There is increase of movement through the range of areas

TABLE II

A. Fluctuation occurs only within a limited range of areas. Results showing the effect of variation of area on the fluctuation of the after-image.

Area	No. of Fluctu-ations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5cm.	0	18.7	18.7	18.7	0	0	18.7
1.5x1.5 "	1	48.6	24.8	49.6	5.5	5.5	55.1
5 x 5 "	2	59.5	21.6	64.8	2.4	4.9	69.7
10 x 10 "	12	21.5	5.9	76.7	2.4	28.8	105.5
20 x 20 "	7	23.5	10.0	80.0	3.2	22.4	102.4
40 x 40 "	3	42.0	16.0	64.0	2.1	6.3	70.3
61 x 50 "	0	72.0	72.0	72.0	0	0	72.0

TABLE III. (Observer W.)

Area	No. of Fluctu-ations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
1 x 1 cm.	2	14.7	20.2	65.5	1.6	3.3	69.8
5 x 5 "	2	18.0	27.9	83.8	1.0	2.0	85.8
10. x 10. "	3	15.5	21.1	85.0	1.0	3.1	88.7
20 x 20 "	6	21.0	11.6	81.3	3.9	11.8	93.1
40 x 40 "	5	8.8	10.5	63.2	4.3	21.45	84.6
61 x 50 "	1	35.5	31.6	63.3	2.6	2.6	65.9
61 x 50 " 55 cm. distant	1	60.0	47.7	95.5	1.0	1.0	96.5
61 x 50 cm. 35 cm. distant	0	50.5	50.5	50.5	0	0	50.5

showing an increase of fluctuations, and decrease where there is a decrease of fluctuation. Nevertheless, the explanation is not so simple as this correlation implies. The effect of eye-movement on fluctuation is not direct. Eye-movement affects the after-image only through its effect on the streaming phenomenon; and the final word of explanation must be deferred until we come to discuss that subject.

Two methods were used for the investigation of eye-move-

TABLE IV. (Observer M.)

Area	No. of Fluctu-ations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
1.5 x 1.5 cm.	0	52.0	52.0	52.0	0	0	52.0
5 x 5 "	2	27.3	18.4	55.2	1.3	2.5	57.7
10 x 10 "	6	35.5	7.9	55.3	2.5	7.5	62.8
20 x 20 "	6	35.0	8.0	56.4	1.3	7.8	62.2
40 x 40 "	5	32.1	8.8	53.1	1.6	8.3	61.4
61 x 50 "	4	42.2	10.5	52.5	1.3	5.3	57.8
61 x 50 " 35 cm. distant	0	52.0	52.0	52.0	0	0	52.0

ment. In the first method, the shifting of the after-image from the stimulus during fixation was chosen as a measure of the eye-movements taking place. This method had the disadvantage that the eye-movement could not be recorded while fluctuation was going on. However, by using only experimental variations that produced marked changes in the steadiness of fixation, by alternating eye-movement with fluctuation records, and by taking a large number of records for each experimental device, this objection was practically obviated; more especially as only comparative results were desired. The method, too, has the very great advantage of sensitivity. When, *e. g.*, the observer is stationed 1 meter from the stimulus, a shift of the after-image 1 mm. to either side represents an eye-movement (measured by the chord of the arc) of approximately .017 mm.[1] The sensitivity of this method is directly proportional to the distance of the observer from the stimulus, and is limited only by the range of distinct vision. Under favorable conditions exceedingly slight tremors can be detected. In fact, as a gauge for small eye-movements, the method is far more sensitive than the methods of photography and of mechanical registration.

In the second method, the after-image was projected without a fixation point, and a record was made of the time during which it was moved and of the time during which it was still. This method was somewhat defective, because the range of movement (a very important factor in the causing of fluctuation) could be indicated only roughly, by the introspective

[1]Calculation is made from the average of the first and second principal focal distances of the normal eye as estimated by Listing: see Helmholtz, Physiol. Optik, 90.

reports of the observers as to whether the after-image moved rapidly or slowly. However, it proved a valuable supplement to the former method, since by it the eye-movements were registered while the fluctuations were actually going on. One could thus tell at once whether disappearance came as a direct effect of eye-movement, *i. e.*, whether it came while the eye was moving or immediately after it had moved; or whether it came in an interval of rest. The effect of vigorous, quick movements could also be compared with that of weaker and slower movements.

Two forms of this second method were employed. In the one, the eye-movement and the phases of appearance and disappearance of the after-image were both recorded; in the other, the eye-movements alone were recorded. The first form gave a direct tracing of the effect of eye-movement upon fluctuation. The recording was done as follows. The after-image was projected without a fixation point, and the key was held down as long as the after-image was in motion and released when it came to rest. When the after-image disappeared, the key was given two quick pressures, and then released until the after-image returned, when the record of movement went on as before until the next disappearance. A certain complication arose with this form of the method. The effort to record both eye-movement and fluctuation seemed to interfere with the course of the after-image, so that fluctuation occurred more frequently than when fluctuations alone were recorded. However, the change was merely a general rise in the scale of frequency. The variations from device to device stood out just as plainly as when the alternative method was used. The reason of the more frequent fluctuations is, probably, that the divided attention necessitated, or rather that the rapidly alternating direction of attention resulted in, a less steady fixation. On this account, the records that were meant to show simply the variation in eye-movement due to the various devices were taken according to the second method: eye-movement alone was recorded. Only these results will be given here, since the others cannot be adequately stated in tabular form,and space forbids the separate publication of every set. The statement must suffice that causal connection between eye-movement and fluctuation is directly evident upon the inspection of the results in question.

For the investigation of the effect of variation of area upon eye-movement, the second method (second form) was used. The after-images were projected without aid from fixation; and the key was held down as long as they were in continuous motion, and released during the intervals in which they were at rest. The following results were obtained.

TABLE V

A. Eye-movement with variation in the area of the stimulus. Showing that an increase in the area of the stimulus first increases, then decreases, the involuntary eye-movement occurring when the after-image is observed.

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving. ÷ Time Still	Rate of Movement
.5 x .5cm.	14.5	4.5	10.0	0.45	Slow
1.5 x 1.5 "	19.5	6.4	13.1	0.48	"
5 x 5 "	28.3	10.5	17.8	0.59	"
10 x 10 "	34.0	26.45	7.55	3.50	Fairly Rapid
20 x 20 "	37.0	20.5	16.5	1.24	Moderate
40 x 40 "	65.2	24.5	50.7	0.59	Slow
61 x 50 "	58.0	19.4	38.6	0.50	"

TABLE VI. (Observer W.)

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
1 x 1 cm.	52.0	15.0	37.0	0.40	Slow
2 x 2 "	58.5	17.1	41.4	0.41	"
10 x 10 "	62.0	23.3	38.7	0.60	"
20 x 20 "	68.0	37.5	30.4	1.23	Fairly Rapid
40 x 40 "	87.0	46.26	40.74	1.13	"
61 x 50 "	96.2	21.3	74.9	0.28	Slow

(2) *Whatever renders fixation unsteady increases the frequency of fluctuation and decreases the duration of the after-image.* The stimulus was a square of standard Hering blue, 3 by 3 cm., fastened upon a large square of engine-gray cardboard. A square of the same cardboard was used as a background upon which to trace the course of the after-image. The effectiveness of the methods employed to disturb fixation was determined by records which showed the range and frequency of the eye-movements produced, and the total time during which the eyes were moving. The methods themselves were five in number. (*a*) The stimulus was fixated at its centre, and the after-image was projected without a fixation-point. (*b*) The stimulus was fixated at its centre, as before, and the after-image

TABLE VII. (Observer M.)

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
1.5x1.5 cm.	50	7.6	41.5	0.18	Slow
5. x 5. "	56	25.0	31.0	0.80	"
10 x 10 "	60	41.5	16.5	2.50	Fairly Rapid
20 x 20 "	58	40.5	19.5	2.08	"
40 x 40 "	60	39.8	20.2	1.98	Moderate
61 x 50 "	58	35.2	22.8	1.54	"
61 x 50 " (35cm. dis.)	57	21.4	35.6	0.60	Slow

was observed by help of a fixation-point. All the observers, with one exception, found the point of service for holding the after-image steady. The exception was Dr. Bair, for whom any effort at muscular control resulted in involuntary twitchings. In his case, therefore, the eye-movement records showed a greater unsteadiness of regard, when effort was made to fixate the point, than when the image was traced upon the blank surface of the cardboard. (*c*) When the after-image was projected without a fixation-point, it tended uniformly to move off in some particular direction, varying with the observer. Whatever be the explanation of this phenomenon (it may possibly be due to a faulty centering of the image upon the retina, itself the result of some maladjustment of the visual mechanism, —movement resulting as a reflex tendency to more accurate fixation), advantage may be taken of it to exaggerate or to correct eye-movement. In order to exaggerate the movement, the direction of the tendency was carefully determined at the beginning of the experimental series. The stimulus was then fixated at a point placed in the line determined by this tendency to movement, but in the *opposite* direction from the centre of the stimulus. Part or all of the stimulus was thus thrown into indirect vision, and the tendency of the after-image to move was increased,—seemingly in proportion of its displacement from the central portion of the field of vision. The reflex movement which tends to centre the after-image in the field of vision added to the natural tendency to movement; and the after-image, projected without a fixation point, moved off rapidly in the direction planned. (*d*) To correct the tendency to movement, the stimulus was fixated at a point placed in the line of the movement, but in the *same* direction from the centre of the stimulus. The consequent displace-

ment of the after-image set up a tendency to movement which counteracted the natural tendency. By careful adjustment it was possible to obtain a fair balance of the two factors, so that the after-image was held steady when projected without a fixation point. Even under the rough conditions of our experiments this adjustment proved, for some observers, the best method of controlling fixation that we could devise.[1] (*e*). For some observers, the best aid to fixation was found to be a square, drawn on the cardboard, of exactly the same size and shape as the after-image, with a point placed at its centre. When the eye moved, the after-image was observed to slip from the square frame; and the observer was thus able to correct the movement before it had attained any considerable range. With the combination of square and central point, the observer had the double advantage of the aid to fixation and the conscious check upon movement. With the point alone, there is little or no conscious control of movement; for the point has to move so far into the field of indirect observation that it is recognized as occupying a different position before the control is operative and the eye can refixate. The distraction to fixation presented by the sides of the square was probably little, because the figure was small enough to be included, practically as a whole, in the field of direct observation. At all events, it did not offset the advantage in the cases of M, A, and Wr.

For A, the after-image, projected without aid to fixation, first moved off slowly to the left, but soon turned sharply and moved much more quickly up and to the right, the latter being the stronger component in the movement. All fluctuations occurred during the second phase. Hence the drift to the left was disregarded in the methods used for correction and exaggeration. To exaggerate the movement, the fixation point was placed 9 mm. below and 12 mm. to the left of the centre of the stimulus. To correct, it was placed 9 mm. above and 12 mm. to the right of the centre.

For B, the after-image moved up and to the right. To exaggerate this movement, the fixation point was placed 12.5 mm. below the centre of the stimulus and 10.5 mm. to the left. To correct, it was placed 8.5 mm. above the centre and 8.5 mm. to the right.

For W, the after-image tended to move up and to the right.

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[1] The direction of the tendency to movement, for the different observers, will be stated in the discussion of the tables. For the students passing through the junior laboratory course, it seems most frequently upward or upward and to the right. The dominant component appears to determine the observer's type as to frequency and range of movement in the horizontal and vertical planes.

TABLE VIII

A. Whatever renders fixation unsteady increases frequency of fluctuation of the after-image and decreases its duration. Whatever aids fixation produces the opposite effect.

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	1	44.0	25.0	50.0	6.0	6.0	56.0
With Point	2	39.2	15.8	47.4	5.7	11.4	58.8
Without Point	3	22.0	10.2	40.8	3.9	11.7	52.5
Exaggerated	5	9.5	4.0	24.0	1.4	7.0	31.0
Corrected	2	36.8	21.5	64.5	4.5	9.0	73.5

TABLE IX. (Observer B.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
With Point	10	17.5	3.1	34.1	1.3	13.0	47.1
Without Point	9	36.0	6.2	62.0	1.2	10.8	72.8
Exaggerated	14	26.0	1.1	16.5	1.0	14.0	30.5
Corrected	8	49.5	9.0	81.0	1.5	12.0	93.0

TABLE X. (Observer W.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	4	13.0	15.2	76.0	.81	3.2	79.2
With Point	3	16.0	22.4	89.6	.55	1.6	91.2
Exaggerated	7	6.0	8.2	65.6	.52	3.6	69.2
Corrected	2	20.7	32.0	96.0	.50	1.0	97.0

Accordingly, to exaggerate this movement, the fixation point was placed 23 mm. below and 23 mm. to the left of the centre of the stimulus. The best correction of the movement was obtained by placing the point 12 mm. above and 6 mm. to the right of the centre. W's records showed an individual peculiarity, in that the first phase of visibility was relatively short, while the last was long. There is no obvious explanation.

TABLE XI. (Observer M.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	5	8.7	7.0	42.0	3.7	18.5	60.5
With Point	2	24.0	24.1	72.3	.67	1.3	13.6
Exaggerated	6	2.4	4.3	30.1	1.1	6.6	36.7
Corrected	1	37.0	29.7	59.4	.9	0.9	60.3

For M, the after-image moved up and to the right. To exaggerate this movement, the fixation point was placed 12 mm. below the centre of the stimulus and 12 mm. to the left. To correct, it was placed 7 mm. above the centre of the stimulus and 7 mm. to the right.

For Wr, the after-image moved up and to the right. To exaggerate this movement, the fixation point was placed 11.5 mm. below and 11.5 mm. to the left of the centre of the stimulus. To correct, it was placed 10 mm. above and 10 mm. to

TABLE XII. (Observer Wr.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	3	81.5	26.5	106.2	2.3	9.2	115.4
With Point	2	92.0	40.3	120.9	1.8	5.4	126.3
Exaggerated	3	45.0	17.2	68.8	1.5	6.0	74.8
Corrected	1	63.5	45.0	90.0	2.5	2.5	72.5
Square	1	71.2	42.0	84.0	2.8	2.8	86.8

TABLE XIII

W. Showing the effects of voluntary control.

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point, No Effort	5	7.0	10.8	64.8	1.4	7.0	71.8
Without Point, Effort	3	16.7	19.9	79.6	1.1	3.3	82.9

the right of the centre of the stimulus. Wr's records showed very long phases of invisibility.

It was found that, when the after-image was projected without a fixation point, frequency of fluctuation was considerably increased if the observer made no particular effort to hold the eyes steady. The following results illustrate this point.

This method showed, more plainly than any other, the effect of a variation in the amount of eye-movement upon the frequency of fluctuation. For this reason, the eye-movements resulting from the various devices employed were studied with some care. Three cases were made of this determination: specimen results will be given from each one.

(1) In order to compare the movements occurring, first, when a point is given for fixation, and secondly when there is no such aid, we had recourse to the shift of the after-image from a colored strip. Strips of Hering's standard yellow, 5 by 50 mm., were pasted on a background of white cardboard, with the shorter dimension in the plane in which the eye-movement was to be investigated. To determine frequency, it was then necessary simply to record the appearance of the after-image to right or left, above or below the stimulus. Separate series were taken for each plane. For the determination of range of movement, narrow strips of paper of the same brightness as the background were pasted successively 2, 4, 6, 8 . . . mm. from the stimulus, and only those movements were recorded that shifted the image up to or beyond them. While the strips were inconspicuous, so that the eye was not drawn away from the fixation point, it was not difficult to observe when the image reached or passed them. The strips were also used when frequency alone was to be determined, in order that the same experimental conditions might obtain throughout. The record was made as follows. When the objects of investigation were the frequency of eye-movement, and the total times during which the eyes maintained and lapsed from their proper fixation, the observer pressed the key as the image appeared to either side of the strip, and held it down until the image was again superposed upon the stimulus. Then the key was released, and so on. Since the eyes may be said to have been in motion for practically the whole period during which the image was not superposed upon the stimulus, the method gives a record of the total time for which the eyes were still and of the total time for which they were moving. When, again, the range of movement was investigated, the key was held down only while the image was out as far as, or beyond, the strips which served as range indicators. These records, therefore, show only the times for which the point of regard was shifted a given distance from the fixation point and for which it was not.

The following tables also inform us of the direction of greatest eye-movement,—information which we need under (4) below.

TABLE XIV

A. Eye-movement: Results showing the movement in the horizontal and vertical planes, with and without a fixation point. Time of observation, 1 min.

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time Eye Moving with Given Range	B. Time not Moving with Given Range	A ÷ B
Vertical	Without Point	Record'd all	85	48.8	11.2	4.35
"	With Point	"	75	33.2	26.8	1.23
Horizontal	Without Point	"	68	41.25	18.75	2.2
"	With Point	"	64	27.3	32.7	0.83
Vertical	Without Point	4 mm.	30	13.0	47.0	0.28
"	With Point	"	25	5.1	54.9	0.09
Horizontal	Without Point	"	13	6.55	53.45	0.01
"	With Point	"	1	0.4	59.6	0.006
Vertical	Without Point	6 mm.	24	8.6	51.4	0.16
"	With Point	"	15	4.3	54.7	0.007
Horizontal	Without Point	"	9	4.75	54.25	0.008
"	With Point	"	0	0	120.0	

TABLE XV. (Observer B; time of obs., 1 min.)

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time Eye Moving with Given Range	B. Time not Moving with Given Range	A ÷ B
Vertical	Without Point	Record'd all	62	32.9	27.1	1.21
"	With Point	"	80	39.1	20.9	1.87
Horizontal	Without Point	"	40	28.8	31.2	0.92
"	With Point	"	56	31.6	28.4	1.11
Vertical	Without Point	2 mm.	16	13.5	46.5	1.29
"	With Point	"	26	19.6	40.4	0.40
Horizontal	Without Point	"	14	10.4	49.6	0.20
"	With Point	"	20	13.1	46.9	0.28
Vertical	Without Point	4 mm.	6	5.2	54.8	0.095
"	With Point	"	14	7.4	52.6	0.14
Horizontal	Without Point	"	2	3.1	56.9	0.054
"	With Point	"	10	5.3	54.7	0.96
Vertical	Without Point	7 mm.	0	0	60.0	
"	With Point	"	4	2.5	57.5	0.043
Horizontal	Without Point	"	0	0	0	
"	With Point	"	2	1	59.0	0.017

TABLE XVI. (Observer W; time of obs., 1 min.)

Arrangement	Fixation	Range of Movement	No. of Movements of given Range	A. Time eye moving with given Range	B. Time not moving with given Range	A ÷ B
Vertical	Without Point	Record'd all	55	40.43	19.5	2.07
"	With Point	"	46	13.67	46.32	0.29
Horizontal	Without Point	"	47	23.4	36.6	0.64
"	With Point	"	35	10.2	49.8	0.20
Vertical	Without Point	2 mm.	45	19.4	40.5	0.48
"	With Point	"	32	9.7	50.25	0.19
Horizontal	Without Point	"	39	14.5	45.5	0.31
"	With Point	"	28	8.27	51.72	0.16
Vertical	Without Point	4 mm.	21	12.2	47.75	0.25
"	With Point	"	16	4.22	57.75	0.07
Horizontal	Without Point	"	16	9.7	50.3	0.19
"	With Point	"	10	3.15	56.85	0.05
Vertical	Without Point	6 mm.	5	1.9	58.1	0.0024
"	With Point	"	3	1.15	58.85	0.0019
Horizontal	Without Point	"	3	1.05	58.95	0.0018
"	With Point	"	0	0	60.0	

TABLE XVII

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time eye moving with given Range	B. Time not moving with given Range	A ÷ B
Vertical	Without Point	Record'd all	28	39.4	20.6	1.91
"	With Point	"	18	22.8	37.2	0.61
Horizontal	Without Point	"	19	30.6	29.4	1.04
"	With Point	"	15	19.5	40.5	0.48
Vertical	Without Point	9 mm.	3	1.5	58.5	0.025
"	With Point	"	2	0.7	59.3	0.011
Horizontal	Without Point	"	2	0.9	59.1	0.015
"	With Point	"	0	0	60.0	

(2) The shift of the after-image from the stimulus was used to determine the eye-movement for each one of the fixation devices. The square of Hering blue paper, 3.5 by 3.5 cm., was observed in turn without a fixation point, with a fixation point placed at its centre, with a fixation point displaced from its centre so as to exaggerate the movement, and with a fixation point so displaced as to correct the movement. Thus frequency and total time of movement were taken account of. Only one table will be given to illustrate these determinations.

TABLE XVIII

W. Showing the effect upon eye-movement of the fixation devices used in Table X. Time of obs., 1 min.

Variation	Time Moving	Time Still	Time Moving ÷ Time Still
Without Fixation Point	27.9	32.0	0.87
With Fixation Point	15.3	44.7	0.34
Exaggerated	38.2	21.8	1.75
Corrected	7.9	53.1	0.15

(3) The eye-movement for each one of the fixation devices was also determined by the second method (second form). The after-image was obtained as in the after-image experiments; and the key was held down as long as the image was moving, and released while it was at rest.

TABLE XIX

A. Showing the effect upon eye-movement of the fixation devices used in Table VIII

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement [1]
Without fixation point	94.9	82.8	12.1	6.84	Moderate
With fixation point	118.0	85.1	32.9	2.58	Movem't slow. Correction jerky
Exaggerated	62.2	58.5	3.7	15.81	Very rapid
Corrected	125.7	68.9	56.8	1.21	Very slow

TABLE XX

B. Showing the effect upon eye-movement of the fixation devices used in Table IX

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
With fixation point	112.5	32.0	80.5	0.39	Movem't slow. Correction jerky
Without fixation point	94.1	47.3	46.8	1.01	Moderate
Exaggerated	50.0	46.6	3.4	13.70	Very rapid
Corrected	159.7	14.7	145.0	0.10	Very slow

(3) *The form of the stimulus affects the frequency of fluctuation.* The stimulus was, as in the former experiments, of standard Hering blue. When squares were used, they were made so small that their edges lay within the field of direct observation; they could thus exert no influence to increase eye-movement, and we should expect a minimal disturbance of the after-image. The strips, on the other hand, were made

[1] The introspections as to rate of movement have not been incorporated in the other sets of eye-movement tables. In general, when the ratio 'time moving ÷ time still' is increased, the rate of movement is also increased.

TABLE XXI

M. Showing the effect upon eye-movement of the fixation devices used in Table XI

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
Without fixation point	84.6	35.1	49.5	0.70	Moderate
With fixation point	100.4	8.3	92.1	0.09	Movem't slow. Correction jerky
Exaggerated	70.2	50.0	20.2	2.47	Very rapid
Corrected	139.0	0	139.0		Very slow

narrow, so that, as their areas were equal to those of the squares, their ends were thrown into the field of indirect observation, and the tendency was towards increased eye-movement. Thus maximal disturbance of fixation was obtained for the given area, and correspondingly a maximal disturbance of the after-image was expected.

To illustrate: a strip .5 x .5 cm. had, as its equivalent area, a square of 1.5 cm.; a strip .5 x 10 cm., a square of 2.2 cm.; a strip .5 x 20 cm., a square of 3.1 cm.; and a strip .5 x 40 cm., a square of 4.4 cm. Only the squares of 2.2, 3.1 and 4.4 cm. fluctuated at all, while the strips showed a rapid increase in fluctuation until .5 by 40 cm. was reached, when a slight decrease occurred. A strip .5 x 20 cm., *e. g.*, gave for A 8 fluctuations, with an average phase of visibility of 7.3 sec.; while its equivalent square gave no fluctuations at all (av. vis., 71.5 sec.). No record was taken of fluctuation in parts; only total disappearances were registered. Thus the actual disturbance suffered by the strip-image was taken account of only in part.

It may be deduced from the following tables that the shape of the curve of frequency obtained by increasing the length of the strips is somewhat different from that obtained by increasing the area of the squares (Tables II-IV). If a curve were plotted by laying off the lengths of the strips along the abscissa and the frequency of fluctuation along the ordinate, the curve would start on or near the abscissa, rise fairly steeply until a length of 20-40 cm. was reached, and then bend downward slightly. It would not reach the abscissa, since with the lengths of strip used fluctuation did not cease as it did with increase of area when squares were used. The reason of this difference between the results of the two sets of experiments will be given later, in our discussion of the streaming phenomenon.

TABLE XXII

A. Form of stimulus affects frequency of fluctuation of after-image. Results showing that fluctuation is more frequent when stimulus is in form of strip, than when it is in form of a square of equivalent area

Form	Area	No. of Fluctuations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Strip	.5 x 2 cm.	0	42.0	42.0	0	42	0	41.5
Strip	.5 x 5 cm.	2	26.0	14.0	1.0	43	2.0	44.5
Square	1.5 x 1.5 cm.	0	52.0	52.0	0	52	0	51.5
Strip	.5 x 10 cm.	6	35.0	8.0	1.2	56	7.3	63.4
Square	2.2 x 2.2 cm.	0	61.0	61.0	0	61	0	61.0
Strip	.5 x 20 cm.	8	26.5	7.3	1.6	66	13.4	79.8
Square	3.1 x 3.1 cm.	0	72.0	72.	0	73	0	71.5
Strip	.5 x 40 cm.	7	26.0	9.5	1.3	76	9.4	85.4
Square	4.4 x 4.4 cm.	3	59.5	19.0	2.0	73	6.0	79.0

TABLE XXIII. (Observer W.)

Form	Area	No. of Fluc-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Square	.5x .5cm.	0	37.2	37.2	37.2	0	0	37.2
Strip	.5x 5 "	2	14.7	15.7	47.2	2.0	4.0	51.2
Square	1.5x1.5 "	1	20.5	33.2	64.5	1.0	1.0	65.5
Strip	.5x 10 "	3	11.5	13.2	55.0	1.4	4.2	59.2
Square	2.2x2.2 "	1	43.0	34.0	68.0	2.5	2.5	70.5
Strip	.5x20 "	3	9.7	15.7	62.8	0.9	2.7	65.5
Square	3.1x3.1 "	2	29.5	23.15	69.5	1.5	3.0	72.5
Strip	.5x40 "	3	11.5	19.2	77.0	2.9	4.4	81.4
Square	4x4 "	2	23.0	24.5	73.5	1.3	3.9	77.4
Strip	.5x61 "	3	6.0	21.8	87.5	3.6	5.5	93.0

TABLE XXIV. (Observer M.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	55.0	55.0	55.0	0	0	55.0
Strip	.5x 5 "	1	59.7	39.6	79.2	1.5	1.5	80.7
Square	1.5x1.5 "	0	66.4	66.4	66.4	0	0	66.4
Strip	.5x10 "	4	32.2	12.5	62.3	2.1	8.4	70.7
Square	2.2x2.2 "	1	58.5	33.0	66.0	4.0	4.0	70.0
Strip	.5x20 "	6	9.2	8.7	61.0	3.2	19.2	80.4
Square	3.1x3.1 "	1	97.0	50.5	101.0	1.0	1.0	101.0
Strip	.5x40 "	6	12.5	7.7	54.5	4.4	26.4	80.9
Square	4.4x4.4 "	2	93.0	32.5	97.5	7.1	14.2	111.7
Strip	.5x50 "	4	20.5	10.2	51.0	3.9	15.6	66.6

The second method (second form) was here used for investigating eye-movement. The squares and strips were projected on a sheet of engine-gray cardboard, without a fixation point, and the times were recorded during which they were moving and at rest.

TABLE XXV

A. Eye-movement, with variation in form of stimulus. Showing that more involuntary eye-movement occurs during obseration of after-image when stimulus is a strip than when it is a square of equivalent area.

Form of Stimulus	Dimensions of Stimulus	Time Ob-served	Time Moving	Time Still	Time Moving ÷ Time Still
Strip	.5 x 5 cm.	24.12	12.02	12.10	0.98
Square	1.5 x 1.5 cm.	35.45	9.40	26.05	0.36
Strip	.5 x 10 cm.	30.00	15.25	14.75	1.03
Square	2.2 x 2.2 cm.	46.80	16.35	30.50	0.53
Strip	.5 x 20 cm.	36.55	24.53	12.03	2.04
Square	3.1 x 3.1 cm.	50.07	19.98	30.72	0.65
Strip	.5 x 40 cm.	38.85	19.50	19.35	1.01
Square	4.4 x 4.4 cm.	55.80	25.50	30.30	0.84

TABLE XXVI. (Observer M.)

Form of Stimulus	Dimensions of Stimulus	Time Observed	Time Moving	Time Still	Time Mov'g ÷ Time Still
Strip	.5x 5 cm.	36.54	14.92	21.62	0.69
Square	1.5x1.5 "	46.90	8.80	38.10	0.23
Strip	.5x10 "	43.25	21.07	22.18	0.95
Square	2.2x2.2 "	49.20	13.30	35.90	0.37
Strip	.5x20 "	49.70	31.23	18.47	1.69
Square	3.1x3.1 "	52.30	19.20	33.10	0.58
Strip	.5x40 "	54.80	35.50	19.30	1.84
Square	4.4x4.4 "	57.90	24.70	33.20	0.74

TABLE XXVII. (Observer W.)

Form of Stimulus	Dimensions of Stimulus	Time Observed	Time Moving	Time Still	Time Mov'g ÷ Time Still
Square	.5x .5 cm.	63.0	15.35	47.65	0.32
Strip	.5x .5 "	64.5	26.20	38.80	0.68
Square	1.5x1.5 "	82.0	21.55	60.45	0.35
Strip	.5x10 "	73.5	33.90	39.60	0.86
Square	2.2x2.2 "	89.0	32.30	56.70	0.57
Strip	.5x20 "	82.0	38.90	42.10	0.90
Square	3.1x3.1 "	89.75	33.50	56.25	0.60
Strip	.5x40 "	97.5	48.25	49.25	0.98
Square	4.4x4.4 "	82.0	35.40	46.60	0.76

(4) *The arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.* The stimuli for A were strips of Hering standard blue, .5 cm. wide and of various lengths; the stimuli for W were strips of 2 cm. wide. These were placed first in the vertical and then in the horizontal plane, and fixated at the centre for 40 sec. The images were observed on a background of engine-gray cardboard, with a fixation point. The tables show more frequent fluctuation, a shorter first phase of visibility, and a shorter total visibility, when the length of the strips is in the vertical plane. Correspondingly, the eye-movement tables show a greater range and frequency in the direction of the lesser dimension of the after-image (the horizontal plane). The results found with the

trained observers have been paralleled in laboratory practice. Those published from this latter class were obtained with Miss Stout (S), a student at Bryn Mawr College.

TABLE XXIX

A. The arrangement of stimulus with reference to direction of greatest eye-movement affects frequency of fluctuation and duration of after-image.

Arrangement of Strip	Dimensions of Strip	No. of Fluctuations	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Vertical	.5 x 5 cm.	2	11.1	33.2	0.5	1.0	34.3
Horizontal	" "	0	47.5	47.5	0	0	47.5
Vertical	.5 x 10 cm.	5	4.0	24.0	0.9	4.5	29.5
Horizontal	" "	1	24.1	48.2	2.9	2.9	51.1
Vertical	.5 x 20 cm.	7	3.8	30.4	1.1	7.7	61.5
Horizontal	" "	1	29.3	58.6	2.9	2.9	38.1
Vertical	.5 x 40 cm.	6	8.7	60.9	0.8	4.8	65.7
Horizontal	" "	3	19.1	76.4	0.7	2.1	78.5

TABLE XXX. (Observer W.)

Arrangement	Area	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	2x5 cm.	2	13.0	16.4	49.2	1.5	3.0	52.2
Horizontal	2x5 "	2	16.5	21.8	65.4	1.6	3.2	68.6
Vertical	2x10 "	2	22.0	17.3	52.0	1.5	3.0	55.0
Horizontal	2x10 "	2	34.5	22.1	66.5	1.4	2.8	69.3
Vertical	2x20 "	3	24.5	16.6	66.5	2.0	6.0	72.5
Horizontal	2x20 "	3	37.0	21.8	87.2	1.3	3.9	91.1
Vertical	2x40 "	4	22.0	16.6	84.0	1.6	6.4	90.4
Horizontal	2x40 "	3	27.6	22.0	88.0	1.4	4.2	92.2
Vertical	2x50 "	3	12.0	16.7	66.8	0.9	3.6	70.4
Horizontal	2x50 "	3	19.5	20.5	82.0	0.7	2.8	84.8

The eye-movement records of A and W, in the horizontal and vertical planes, are given in Tables XIV, XVI. In both cases, for every point recorded, there was marked excess in the horizontal plane. Owing to lack of time this determination was not made for S. The fact, however, that in S's duplication series the eye-movement across the strip was always more

TABLE XXXI. (Observer S.)

Arrangement of Strip	Dimensions of Strip	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	.5x 5 cm.	2	14.2	9.6	28.8	2.6	5.2	34.0
Horizontal	.5x 5 "	1	32.0	17.4	34.8	4.0	4.0	38.8
Vertical	.5x10 "	3	12.6	7.5	30.0	2.1	6.3	36.3
Horizontal	.5x10 "	2	28.9	13.6	40.8	3.5	10.5	51.3
Vertical	.5x20 "	8	10.4	5.6	50.4	1.5	12.0	62.4
Horizontal	.5x20 "	4	27.2	13.3	65.5	2.4	9.6	75.1
Vertical	.5x40 "	5	24.5	9.8	58.8	4.0	20.0	78.8
Horizontal	.5x40 "	3	30.4	16.4	65.6	4.6	13.8	79.4

effective for fluctuation than that along it indicates that the greater frequency of fluctuation when the strip was arranged vertically was due to an excess of eye-movement in the horizontal plane.

(5) *The results in (1), (3) and (4) can be roughly duplicated by using voluntary eye-movement to cause the disappearances.* The voluntary eye-movement was regulated throughout in the following manner. The after-image was observed with the aid of a fixation point. A second point was placed 12 cm. to the right of this. At a signal, given every 3 sec. by the experimenter, the observer moved his eyes quickly out to this point and back again. He was told to record as a 'disappearance' only a case in which the after-image failed to reappear after the eyes had regained their normal fixation. Thus nothing but genuine disappearances were taken account of. Possible visual synæsthesia attending eye-movement, distraction, etc., were guarded against by the directions under which the observer worked. The after-images were blotted out as completely as after-images ever are in the case of natural fluctuation. There is not a shadow of doubt on this point. The more uniform side of engine-gray cardboard was used as background for both stimulus and after-image. Hence there was no danger of disturbance by possible distractions due to movement of the eye over an irregularly marked surface.

i. Fluctuation occurs only within a limited range of areas. Just as when the observation is made under the conditions of ordinary fixation, the after-effect of general adaptation does not fluctuate under the influence of voluntary eye-movement. Nor do after-images fluctuate beyond a comparatively limited range of areas. Within this range the results are very similar to those obtained in the case of natural fluctuation. Large images do not fluctuate at all; small images little, if at all;

while middle-sized images alone fluctuate readily. The curve of frequency takes the same general shape as it does with natural fluctuation.

TABLE XXXII

A. Duplication of results by voluntary eye-movement. Method of variation of area.

Area	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5 cm.	0	35.5	35.5	35.5	0	0	35.5
1.5x1.5 "	1	54.5	30.0	60.0	0.6	0.6	60.6
5x5 "	3	59.0	18.2	72.8	1.5	4.5	77.3
10x10 "	13	23.2	6.5	91.0	0.7	9.1	100.1
20x20 "	12	32.0	6.2	80.6	0.6	7.2	87.8
40x40 "	2	78.5	30.5	91.5	0.9	1.8	93.3
61x50 "	0	89.7	89.7	89.7	0	0	89.7

TABLE XXXIII. (Observer W.)

Area	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
.5 x .5 cm.	0	33.0	33.0	33.0	0	0	33.0
1 x 1 "	3	26.2	10.0	40.2	0.55	1.7	41.9
5 x 5 "	7	11.5	5.2	43.3	0.75	5.3	48.6
10 x 10 "	14	19.4	5.0	75.9	0.6	7.9	83.8
20 x 20 "	13	20.2	3.7	52.0	1.6	21.1	73.1
40 x 40 "	0	82.0	82.0	82.0			82.0
61 x 50 "	0	69.5	69.5	69.5			69.5

TABLE XXXIV. (Observer M.)

Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5 cm.	0	47.0	47.0	47.0	0	0	47.0
1.5x1.5 "	0	71.0	71.0	71.0	0	0	71.0
10x10 "	11	54.5	6.5	82.5	2.0	22.8	105.3
20x20 "	11	31.5	5.2	63.1	1.5	17.1	80.2
40x40 "	10	37.0	5.4	60.0	1.3	13.6	73.6
61x50 "	0	46.0	46.0	46.0	0	0	46.0

ii. The form of the stimulus affects the frequency of fluctuation. The same set of stimuli were used as for natural fluctuation, and all the other conditions of the experiment were kept as nearly as possible the same. It will be observed that here, as before, the squares fluctuated little, if at all, while the strips increase in frequency of fluctuation with increase of length until a certain point is reached, when a slight decrease takes place.

TABLE XXXV

A. Duplication of results by voluntary eye-movement. Results showing that fluctuation is more frequent when stimulus is a strip than when it is a square of equivalent area.

Form	Area.	No. of Fluc-tuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Strip	.5 x 2 cm.	0	38.5	38.5	38.5	0	0	38.5
Strip	.5 x 5 "	3	6.2	12.5	50.0	4.0	1.2	51.2
Square	1.5 x 1.5 "	0	49.0	49.0	49.0	0	0	49.0
Strip	.5 x 10 "	4	3.3	8.5	42.5	0.3	1.2	43.7
Square	2.2 x 2.2 "	0	56.0	56.0	56.0	0	0	56.0
Strip	.5 x 20 "	7	2.5	7.6	60.8	0.35	2.2	63.0
Square	3.1 x 3.1 "	1	67.0	35.8	71.6	1.9	1.9	73.5
Strip	.5 x 40 "	5	4.5	11.1	66.6	0.39	1.9	68.5
Square	4.4 x 4.4 "	2	66.0	24.5	73.5	1.1	2.2	75.7

TABLE XXXVI. (Observer W.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	40.5	40.5	40.5	0	0	40.5
Strip	.5x5 "	3	23.5	18.5	74.0	1.2	3.6	77.6
Square	1.5x1.5 "	1	38.5	31.3	62.6	1	1	63.6
Strip	.5x10 "	4	14.0	13.7	68.5	1.9	5.7	74.2
Square	2.2x2.2 "	1	32.6	28.2	56.4	1.5	3	59.4
Strip	.5x20 "	4	16.9	14.0	70.0	1.5	6.0	76.0
Square	3.1x3.1 "	2	29.4	26.3	78.9	1.2	2.4	81.3
Strip	.5x40 "	3	23.0	21.1	84.4	1.8	5.4	89. 3
Square	4.4x4.4 "	3	26.2	23	92	1.3	3.9	95.9

TABLE XXXVII. (Observer M.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	48.3	48.3	68.3	0	0	68.0
Strip	.5x5 "	5	56.0	12.6	75.6	1.0	5.0	80.6
Square	1.5x1.5 "	0	68.2	68.2	68.2	0	0	68.2
Strip	.5x10 "	9	36.6	6.7	67.0	1.2	10.8	77.8
Square	2.2x2.2 "	2	55.6	23.3	69.9	2.0	4.0	73.9
Strip	.5x20 "	11	11.4	5.4	64.8	1.1	12.1	76.9
Square	3.1x3.1 "	3	82.6	26.0	104.0	2.4	7.2	111.2
Strip	.5x40 "	11	11.9	5.2	62.4	1.2	13.2	75.6
Square	4.4x4.4 "	4	86.6	19.6	98.0	2.4	9.6	107.6

iii. The arrangement of the stimulus with reference to the direction of greatest eye-movement influences the frequency of fluctuation and the duration of the after-image. Again, the same set of stimuli were used as for natural fluctuation, and the other conditions of the experiment were kept the same. For W the eye-movement was given in the horizontal plane with both arrangements of the stimuli. The tables show that when the strip was arranged with its length in the vertical plane, so that the movement was directed along its shorter dimension, the fluctuations were more frequent and the duration was shorter.

TABLE XXXVIII

W. Duplication of results by voluntary eye-movement. Showing that the arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.

Arrange-ment	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	2 x 5 cm.	2	12.9	11.1	33.3	0.7	1.4	34.7
Horizontal	2 x 5 "	2	17.4	16.6	49.8	1.1	2.2	52.0
Vertical	2 x 10 "	3	22.8	10.2	40.8	0.8	2.4	43.2
Horizontal	2 x 10 "	3	33.6	15.4	61.6	1.0	3.0	64.6
Vertical	2 x 20 "	4	25.5	8.9	44.5	0.7	2.8	47.3
Horizontal	2 x 20 "	4	39.0	13.2	66.0	0.9	3.6	69.6
Vertical	2 x 40 "	5	22.4	9.2	55.2	0.8	4.0	59.2
Horizontal	2 x 40 "	5	38.6	15.0	90.0	1.2	6.0	9.6
Vertical	2 x 50 "	5	18.2	8.7	52.2	1.1	5.5	57.7
Horizontal	2 x 50 "	4	26.3	14.8	74.0	1.3	5.2	79.2

The law that eye-movement, when directed along the lesser dimension of the after-image, is more effective to produce fluctuation and to shorten duration was given a still more thorough verification in the cases of A and S. The strip was

TABLE XXXIX. (Observer A.)

Arrange-ment of Strip	Dimensions of Strip	Direction of Movement	No. of Fluct-uat's	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Horizontal	.5x10 cm.	Vertical	4	3.3	16.5	0.8	3.2	19.7
"	"	Horizontal	3	14.8	59.2	0.9	2.7	61.9
Vertical	"	Horizontal	5	5.8	34.8	0.5	2.5	37.3
"	"	Vertical	1	22.0	44.0	1.4	1.4	45.4
Horizontal	.5x20 cm.	Vertical	8	5.1	45.9	0.6	4.8	50.7
"	"	Horizontal	1	25.0	50.0	0.5	0.5	50.5
Vertical	"	Horizontal	6	3.2	22.4	0.6	3.6	26.0
"	"	Vertical	2	16.4	49.2	1.1	2.2	51.4
Horizontal	.5x40 cm.	Vertical	3	13.2	52.8	0.4	1.2	54.0
"	"	Horizontal	1	34.7	69.4	0.3	0.3	69.7
Vertical	"	Horizontal	6	4.0	28.0	0.4	2.4	30.4
"	"	Vertical	4	10.1	50.5	0.5	2.0	52.5

placed with its length in the horizontal plane, and eye-movement prescribed first in the vertical and then in the horizontal plane. Then the strip was placed with its length in the vertical plane, and movement prescribed first in the horizontal and then in the vertical plane. It is thus shown that the law is not dependent upon the plane in which the strip is arranged, or the direction of the eye-movement, but that the only essential condition is that the movement be along the lesser dimension of the after-image.

TABLE XL. (Observer S.)

Arrangement of Strip	Dimensions of Strip	Direction of Movement	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	.5 x 10cm.	Horizontal	5	21	5.9	35.4	2.6	13.0	48.4
"	.5 x 10 "	Vertical	2	30	14.3	42.9	3.2	6.4	49.3
Horizontal	.5 x 10 "	"	4	34	9.0	45.0	2.0	8.0	53.0
"	.5 x 10 "	Horizontal	3	42	13.7	54.8	3.3	9.9	64.7
Vertical	.5 x 20 "	"	16	19	4.1	69.7	2.0	32.0	101.7
"	.5 x 20 "	Vertical	9	43	7.9	79.0	2.7	24.3	103.3
Horizontal	.5 x 20 "	"	8	35	7.3	65.7	1.7	13.6	79.3
"	.5 x 20 "	Horizontal	6	58	11.5	80.5	2.7	16.2	96.7
Vertical	.5 x 40 "	"	8	45	8.7	78.3	2.6	20.8	99.1
"	.5 x 40 "	Vertical	5	56	14.1	84.6	3.1	15.5	100.1
Horizontal	.5 x 40 "	"	6	63	13.3	93.1	2.0	12.0	105.1
"	.5 x 40 "	Horizontal	4	78	20.0	100.0	2.3	9.2	109.2

(6) *An increase in the time of stimulation increases the number of fluctuations of the after-image.* Hering standard blue, 10 by 10 cm., was used as stimulus for A and M; the same

TABLE XLI

A. Increase of time of stimulation increases frequency of fluctuation of after-image.

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
10 sec.	1	42.0	27.5	55	5.4	5.4	60.4
40 "	4	78.4	23.8	119	3.1	12.4	131.4
70 "	7	97.6	20.2	162	2.4	16.8	178.8
90 "	8	94.3	17.4	157	2.1	16.8	173.8

blue, 5 by 5 cm., was used for W. The stimulus was placed on a square of engine-gray cardboard, and fixated at its centre. The after-image was projected upon a similar cardboard, with a fixation point.

It will be noticed that, with a stimulation of 10 sec., the after-image began fluctuating 8.4 sec. before its final disappearance; with 40 sec., 53 sec. before; with 70 sec., 81.2 sec. before; and with 90 sec., 87.5 sec. before disappearance. Increase in the time of stimulation results, then, in the after-image beginning to fluctuate at a greater intensity. If this result is taken in connection with the proof of an increase of eye-movement for the longer times of stimulation, it affords a strong indication that eye-movement causes fluctuation. The conclusion is made almost positive by the fact that increase of intensity, without increase of time of stimulatiom, does not increase fluctuation.

TABLE XLII. (Observer W.)

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
10 sec.	0	23.9	23.9	23.9	0	0	23.9
40 "	2	13.3	19.3	38.7	1.7	3.4	42.1
70 "	3	22.1	16.8	64.4	1.7	5.1	69.5

The table shows that with a stimulation of 10 sec. the after-image did not fluctuate at all; with 40 sec. it began to fluctuate 28.8 sec., and with 70 sec., 47.4 sec. before final disappearance.

TABLE XLIII. (Observer M.)

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
10 sec.	0	18.0	18.0	18.0	0	0	18.0
40 "	4	42.0	10.7	53.5	3.0	12.0	65.5
100 "	6	48.0	9.8	68.8	3.2	19.0	87.8

An inspection of the table will show that with a stimulation of 10 sec., the after-image did not fluctuate at all; with 40 sec., it began to fluctuate 23.5 sec., and with 100 sec. 39.8 sec. before it finally disappeared.

That increase in eye-movement follows increase in the time of stimulation was proved by the second method for the investi-

gation of eye-movement: *i. e.*, by a direct record of the movement of the projected after-image. The following results were obtained.

TABLE XLIV

A. Eye-movement with variation in time of stimulation. Showing that increase in time of stimulation increases the involuntary eye-movement occurring when after-image is observed.

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	14.7	4.95	9.75	0.5
70 "	54.5	26.4	28.1	0.94
100 "	41.0	23.0	18.0	1.28
130 "	52.2	30.4	22.3	1.36
180 "	46.0	24.4	21.65	1.12

TABLE XLV. (Observer W.)

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	64.35	22.75	41.6	0.54
40 "	85.0	29.0	46.0	0.85
70 "	96.5	48.35	48.2	1.0
130 "	102.0	55.3	46.7	1.16
190 "	95.0	59.85	35.15	1.7

TABLE XLVI. (Observer M.)

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	22.5	3.25	19.25	0.11
40 "	61.0	25.75	35.25	0.73
70 "	52.4	29.65	22.75	1.30

It was stated under the heading 'Results: General' that increase in the time of stimulation gave three results: it increased

the intensity of the after-image, the amount of involuntary eye-movement, and both the number of fluctuations and the intensity at which fluctuation began. In order to determine positively which of the two first is the cause of the third, it was necessary to study the effect of increase of intensity in isolation, *i. e.*, to increase intensity without increase of involuntary eye-movement. Since increase in involuntary eye-movement is found to follow increase in time of stimulation, the increased intensity must be secured without increase of stimulation time. This was done as follows: Hering-gray, no. 31, was used as stimulus background. Squares 5 by 5 cm. of Hering grays 15 and 7, and of Hering white, were used in turn as stimuli. The intensity of the stimulus in this case is measured by its difference from the background. Thus the intensities, roughly at least, stood in the relation 16 : 24 : 31. A square of Hering gray no. 15 was used as the background upon which to project the after-images. This shade of gray was selected because it corresponded approximately to the after-effect of the stimulus background. Thus the projection background was kept constant until the after-image, whose fluctuations were being observed, finally disappeared. This precaution may not have been necessary, but it seemed well to plan the experiment as carefully as possible. The time of stimulation was 40 sec. throughout. All these conditions were the same for the different stimuli.

A typical set of averages has been selected for publication. It will be observed that increase of intensity, without increase in time of stimulation, does not increase either the number of fluctuations, or the intensity at which fluctuation begins. Hence these results, when obtained with increase in time of stimulation, must be due to increase of eye-movement.

TABLE XLVII

A. Results showing that increase in intensity does not increase fluctuation of after-image.

Stimulus	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Hering Gray No. 15 on " " " 31	5	20.3	7.4	44.4	2.7	13.5	57.9
Hering Gray No. 7 on " " " 31	5	22.0	9.3	55.8	1.9	9.5	65.3
Hering White on " Gray No. 31	3	28.0	15.6	62.4	2.3	6.9	69.3

(7) *The observers most sensitive to the methods used to disturb fixation show the widest range of variability in fluctuation and duration.* This will be seen by a comparison of the eye-movement with the after-image tables for each of the observers and for the various methods used. Dr. Bair (B) and Miss Alden (A) were the most sensitive; the Misses Montgomery (M) and Wright (Wr) the least; and Miss Walter (W) was of intermediate sensitivity.

(8) *Increase of practice in fixation brought with it a decrease in the frequency of fluctuation and an increase in the duration of the after-image.* Space does not permit us to show in detail this falling off in sensitivity of the different observers as the work progressed. It will be sufficient to say that it was quite marked.

iii. *How does eye-movement cause the fluctuation and shorten the duration of the after-image?*

a. It is evident that neither Fechner's nor Helmholtz' theory is adequate to the results given in the preceding Sections. Changes in illumination (Helmholtz) do not account for the shape of the curve of frequency for variation of area. Nor do they explain the fluctuation of the after-image in parts, or the effect produced upon fluctuation by variations in the form and arrangement of the stimulus. Fechner's theory, that eye-movement arouses vascular and nervous disturbances which in turn react upon the after-image, is, first of all, too indefinite. We are not told how these disturbances work, and no tangible evidence is adduced that eye-movement produces them. In the second place, even if the disturbances are granted, it is difficult to understand why they take place in this and that part of the retina while the remainder is not affected (fluctuation in parts); why they are effective in the case of certain areas, and not at all in that of others (effect of variation of area on fluctuation); and, still more, why the form of the stimulus, and its arrangement with regard to the direction of greatest range and frequency of eye-movement, etc., affect the fluctuation and duration of the after-image as powerfully as they are found to do.

Fick and Gürber follow a different course. They study the relief of adaptation not, like Helmholtz and Fechner, from the side of the negative after-image, but from the positive side. They show in various ways that the color or brightness of a stimulus to which the eye has been adapted is restored by eye-movement. They contend that adaptation is a phenomenon of fatigue, and that eye-movement relieves it, chiefly, by facilitating the removal of the fatigue products from the retina; less importantly, by increasing the delivery of new material to the

fatigued end-organs. This hypothesis, though perhaps the most promising of all the eye-movement theories, is at the same time scarcely less speculative than the others. The passage of lymph to and from the retinal elements is a necessary postulate of metabolism; but Fick and Gürber give no direct or positive proof that eye-movement facilitates the exchange; nor has the proof been brought by any subsequent investigator.

Vascular disturbances in the retina are alleged as *indirect* evidence. The following authorities may be cited upon this point. On the negative side, we find A. Coccius (Ueber die Anwendung des Augenspiegels, etc., 1853, 20), who was the first to investigate the matter, asserting that the disturbances are not present in the case of quick, short eye-movements. O. Becker (Archiv f. Ophthalmol., XVIII, 1, 1872, 242) contends that eye-movement exerts no especial influence, since he finds fluctuations in the caliber of the retinal vessels when the eye-muscles are paralyzed by atropine. On the positive side, A. v. Graefe (Archiv f. Opthalmol., I, 2, 1855, 387) establishes the general principle that eye-movement causes an increase of pressure in the vitreous humor; hence every change of fixation is followed by an increase of vascular pulsation in the retina. Michell (Lehrbuch der Augenheilkunde, 1. Aufl., 547) observed that eye-movement causes a paling of the retinal capillaries. W. Dobrowolsky (Centralblatt f. d. medic. Wissensch., 1870, 20 and 21), working on a dog, observed frequent changes in the calibre of the retinal capillaries. These changes disappeared, however, when motor paralysis was produced by curare; the capillaries also became paler when the eye-muscles were electrically stimulated. Fick and Gürber themselves, working both on the human eye and on the eyes of dogs, were able in some cases to observe the effect of eye-movement on the calibre of the retinal vessels. They found, *e. g.*, in the case of the human eye, that when the eyes are held steadily upon some distant object, vascular changes are not noticeable, but that noticeable changes occur when the eyes are moved. They believe that these changes are not normal pulsations due to the heart's action, but are directly caused by the eye-movements. The natural pulse, they say, is not observable for various reasons: thus, it may possibly be obscured by the rapidity of the heart's action. This supposition seems to receive confirmation from the results of experiments on dogs. When the dogs were put under the influence of chloral or morphine, and all the eye-muscles severed, a rhythmical change in the calibre of the retinal vessels was plainly noticeable. Since eye-movement could not operate to produce this rhythm, they regard it as that of the natural retinal pulse, now rendered observable through the slowing of the heart's action by the drugs used. On the whole, however, and having regard both to their own work and to that of others, Fick and Gürber did not consider the evidence that eye-movement influences retinal circulation to be entirely satisfactory.

Moreover, if we look at the problem from the side of the negative after-image, the hypothesis can apparently be of service only in explaining the effect of eye-movement upon the total duration of the after-image. Facilitation of the removal of fatigue products does not account for fluctuation; for if the fatigue material is carried away so completely as to cause the disappearance of the after-image, there is no satisfactory or plausible reason why it should accumulate again, and cause the

after-image to reappear, when the eye has in the meantime undergone no additional stimulation.[1] Since, then, the hypothesis cannot explain a simple case of fluctuation, it manifestly cannot account for the variations in the phenomenon discussed in the foregoing pages;[2] and, failing in this regard, it manifestly has not taken into consideration all the factors that operate to relieve adaptation.

b. Much to our surprise, the solution of the problem came with the observation of a phenomenon which, for want of a better term, will be called the 'streaming phenomenon.' We turn to its consideration with the reluctance that a writer must feel in pointing out a new phenomenon in a field so old and so minutely canvassed as that of vision, but nevertheless with a full sense of responsibility. The phenomenon was first observed in 1905, and since that time has been carefully investigated by the writer with the aid of nine observers: seven students of psychology and two laymen. All were sceptical at the outset; but later, independently of one anothers' and of the writer's observations, were able to describe the phenomenon in detail, and to sketch the more prominent of the multitude of stream patterns.

1. A brief description is difficult. When one sits with lightly closed lids, which must be kept from quivering, before a bright diffuse light, such as that of a partly clouded sky,

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[1] Fick and Gürber do not treat their problem from the side of the negative after-image, nor are they primarily concerned with this aspect of adaptation (especially with the fluctuation of the negative after-image); at the same time, they offer an explanation of this fluctuation. The explanation, however, does not account for the various cases and types of fluctuation; and its basis is both hypothetical and, in terms of the results of our own observers, contrary to fact. It runs as follows: "Augenbewegungen und Accommodation quetschen die Netzhaut gleichsam aus, das negative Nachbild verschwindet. Aber nicht aus der ganzen Netzhaut werden die Stoffwechselproducte entfernt, sondern nur aus der empfindlichsten Schichte; darum taucht das negative Nachbild in demselben Masse wieder auf, in dem sich die Stoffwechselproducte wieder über die empfindlichste Netzhautschichte verbreiten" (Archiv f. Ophthalmol., XXXVI, 300). Observation shows rather that instead of the waste material being forced from the after-image area by eye-movement, and returning to it when the intraocular pressure is relieved, just the reverse movement of material takes place. That is, eye-movement causes a wash of material from some part of the surrounding retina over the after-image area. As long as this streaming material is passing over the area, the after-image cannot be seen. When it has passed beyond it, the image reappears.

[2] It is not clear, *e. g.*, why the waste material forced from the after-image area does not return, to cause the reappearance of large and small after-images, as it does so readily in the case of after-images of medium area. Similar difficulties, too obvious to need separate mention, are encountered in the other cases discussed above.

and looks deep into the field of vision thus presented, beyond the background as usually observed, one sees about the point of regard, after the field of vision has steadied, slowly moving swirls.[1] These swirls have the appearance of streams of granules moving in broad curves now this way, now that, seemingly without order unless a noticeable eye-movement occurs, or is made voluntarily, when the direction of streaming changes to that of the eye-movement.[2] The change of direction is always on a curve, the abruptness of which depends upon the vigor of the movements, much as would happen if motions in different directions and of different magnitudes were compounded at intervals upon a fluid of considerable inertia. The phenomenon is extremely varied. Sometimes the central portion of the field of vision resembles the surface of a liquid about to boil, channeled this way and that by convection cur-

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[1] The manner in which the lids are held is of extreme importance. They must not be closed so tightly that pressure is exerted on the eyeballs, and on the other hand, they must not admit light. It is difficult at first to find just the right background and the proper illumination. Quivering of the lids is fatal to the observation. The writer's only failure to secure a successful observation was on the part of an observer who could not keep the lids from trembling. Such painstaking precautions are necessary, however, only until the observer has once seen the phenomenon. Afterwards there is no difficulty. In fact, like the entoptic and circulation phenomena, the streaming may even become troublesome by its insistence. The plane of fixation is a matter of peculiar consequence. One must look through and beyond the shifting, changing, indefinite haze that occupies the visual foreground of the closed eyes. No better direction can be given than that the observer try to resolve this haze, to find out what lies in and behind it. He must gaze intently and penetratingly. Since the smoothest part of the closed lid lies above the centre of the eye, it is of advantage to look slightly upward, instead of directly forward. The steady field of vision should reveal the streaming, but voluntary eye-movement, by increasing its activity, frequently facilitates the observation. If one moves the eye sharply, and intently watches the field of vision in the trail of the movement, one sees (sometimes immediately following and sometimes lagging behind) a stream which takes the general direction of the movement. By way of final caution, we cannot emphasize too thoroughly the need of persistence and patience in observing. An unpractised observer should not expect to see the phenomenon in less than 2-5 minutes after closing his eyes. The field of vision must clear and settle, and the observer must grow accustomed to the unusual conditions of observation.

[2] The real movement of the streaming is in the opposite direction to that of the retina. The apparent motion of the eye is the movement of its anterior portion. This is opposite to the movement of the retina; hence the streaming material seems to pass across the field of vision in the direction in which the eye is moving. It might, of course, be expected that a mobile material on the retina would move under the influence of eye-movement as the streaming material is thus found to do.

rents moving at varying rates of speed. Now and again a heavy stream will sweep across this channeled surface from one direction or another, taking up the minor swirls as sharply curving tributaries, and so on, through manifold changes. Various patterns can be picked out, and a particular swirl may be traced in its deviations for a time; but, as a whole, the phenomenon cannot be adequately described.

After practice on the closed lids, the observers became able to trace the streaming on any dull or rough surface with the eyes open. It may also be observed under the conditions of observation of the entoptic and circulation phenomena; but just as one must look beyond the false scotomata to see the moving corpuscles and interspaces, so must one look beyond them to see the streaming. So competent did certain observers become, with the eyes open, that records were made in the experiments with minimal stimuli of the time that heavy streaming lasted during the phases of invisibility.[1]

2. In casting about for a physiological explanation of the streaming phenomenon, we have been led to believe that it is caused by a streaming over the retina of some material which is capable of directly affecting the processes that condition visual sensation. First, on the negative side, we find that it cannot be a circulation, entoptic, or tear-film phenomenon, or any of the shadow phenomena; for it is seen in the dark as well as in the light. In fact the best way to observe it, with the eyes open, is in the dark room or in a carefully muffled blackness cylinder. Secondly, on the positive side, we have three facts to consider. The streaming occurs, as we have just mentioned, in the dark as well as in the light. It is seen in the dark as a streaming and swirling of the intermingled blackness and luminous haze that compose the visual field. Here it must directly excite the black-white process. Again, the streams carry with them the quality of the background from which they proceed. This fact may be demonstrated as follows. Get upon the retina a large square blue after-image, having through its centre a vertical strip of yellow. Projected upon the field of vision afforded by the closed lids in daylight, this image will be seen as a strip of reddish yellow on a background of purple. A heavy stream, in passing across the strip, will sweep the purple with it across the yellow, and will deposit traces of the yellow in irregular patches on the further side. In other cases, where a heavy swirling takes place over the strip area, the yellow will break up irregularly, traces and

[1]The phenomenon comes out with remarkable clearness with open eyes, in the blackness of the dark room. The field of slightly luminous haze that there confronts one for some minutes, at a certain distance, streams and swirls with convincing distinctness.

patches of its color being borne out in different directions, and the background swept in. In yet other cases, the swirl will form outside the image, and sweep across it, much as a swirl of snow is carried before the wind. In all of these variations of stream-type, however, it is the unfailing rule that the quality of the background is carried by the stream from point to point in its course. Lastly, the streaming has a characteristic effect upon the after-image. Gentle streaming dims the after-image, apparently in proportion to its vigor, provided that it comes from an area of different visual quality, but heavy streaming blots it out absolutely. This occurrence, once seen, can never be doubted. The observation is positive.

3. The effect of streaming is the same, whether the eyes are open or closed. It is true that the stream is not so clearly seen to sweep over the after-image when this is projected on a background with the eyes open, as when it is projected on the field of the closed lids. Nevertheless, the instant that the image disappears, streaming can always be plainly seen over the area which it occupied. If the background is a rough, dull surface, the stream can even be seen to form and pass across the image. Most of our observers readily noticed this phenomenon, and some reported it before they had discovered streaming in the field of the closed lids, so that it formed their first observation of streaming.[1]

We have, further, indirect evidence of the identity of fluctuation under the two conditions of projection, in the striking

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[1] A word of explanation here may prevent misunderstanding. What was observed, with the eyes open, was that the background seemed to sweep over this or that part of the after-image area, and that as the stream advanced the color disappeared. The stream seemed, decidedly, to sweep the color out, or at least to be causally connected with its disappearance. The phenomenon is, naturally, less striking than it is when the after-image is seen on the field of the closed lids. For one thing, the image is now projected on a field some distance away; the streams are thus magnified, and accordingly rendered vague and diffuse, less distinct in form and outline. For another thing, the brightness of daylight illumination tends to obscure the phenomenon. And other factors in the result could probably be mentioned.

Many of the brief disappearances of visual stimuli, especially those of positive stimuli of considerable intensity, are seen to be caused in the same way by streaming. The stream sweeps over them and blots them out; as it passes off, they reappear from behind, slightly farther back. The latter phenomenon is especially noticeable in the case of the shadows cast by a false scotoma on the retina.

Similar observations may be made in the course of adaptation experiments. Lay, *e. g.*, a fairly dark disc of Hering gray on a background of Hering gray several shades darker. While the disc is leveling down to the background, this or that portion of it will be repeatedly swept out by streams, moving across it in a curve. Many of the writer's laboratory students at different colleges have reported this phenomenon.

correspondence which obtains between the types of disappearance when the image is observed, as is ordinarily done, on a cardboard or other background, and when it is traced on the field of the closed lids in conjunction with streaming. Parallel series of experiments were carried out with after-images in the form of strips, squares, and crosses, large and small, projected both upon a background of cardboard and upon the field of the closed lids. The result was that, if a sufficient number of cases is considered, every type of disappearance found in the one series can be found also in the other. The following paired observations, selected at random, will illustrate this correspondence.

Stimulus: Milton Bradley standard yellow, 42 by 4 cm. After-image observed on background of engine-gray cardboard. Time of stimulation 30 sec. Distance of *O* 1 meter.

After-image dimmed over its whole area. Revived. Bottom went out. Reappeared. Whole image went, disappearing first along right edge in form of a curve, convex inwardly, then spreading. Reappeared, beginning along right edge. Top disappeared. Reappeared almost immediately. Top and bottom went out almost simultaneously, slowly followed by centre. (These disappearances rarely if ever occurred over the whole area at once. They began in a certain part, and then extended; one could see the area in process of being swept over. The parts disappearing were always bounded by curved lines.) Bottom came back first. Upper part disappeared, central and lower part dimmed, but did not disappear. Reappeared. Centre went out; then bottom. Quickly reappeared. Whole after-image disappeared, beginning in lower right-hand corner and spreading towards the top. Faintly reappeared. Vanished.

Stimulus: Milton-Bradley standard yellow, 42 by 4 cm. After-image observed on the field of the closed lids. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gentle streaming aud dimming over the whole area of the after-image. Upper half and centre swept out by a swirl moving counter clockwise, and carried across from the left. Reappeared. Whole after-image blotted out by two streams moving from left and right, joining, and moving upwards for the whole length of the after-image. Cleared over whole area, beginniug at bottom. Lower part swept out by a stream moving obliquely down and to left. Almost immediately another swept up and to right, carrying out centre and upper half. Reappeared. Swirl counter-clockwise cut off top. Reappeared. Stream moving on a very gradual curve to right from above cut out all but right edge of lower half. Finally this became involved. Cleared. Heavy stream moved across centre from right, blotting it out; divided and swept back on itself obliquely towards top and bottom,carrying out whole after-image. General commotion. Dimmed. Unable to follow changes farther.

Stimulus: Milton-Bradley yellow, 10 by 10 cm. After-image observed on engine-gray cardboard. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gradually dimmed. A curved segment was blotted out of left side. Reappeared. Disappeared, beginning with top. Reappeared, beginning with upper right-hand corner. Disappeared, beginning with top and upper left corner. Left side came back first, then whole image. Disappeared, beginning at top. Lower left corner went next.

Lower right corner was slow to go. Reappeared, beginning with lower left corner. Disappeared again almost immediately. Reappeared, beginning at bottom. Quickly disappeared. Reappeared faintly; then vanished.

Stimulus: Milton-Bradley yellow, 10 by 10 cm. After-image observed on field of closed lids. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gentle general streaming dimmed after-image. Lower right-hand corner cut off by streams, moving on short curves. Cleared. Stream from below moving from right to left swept out lower right corner and bottom. Cleared. Stream swept from right upper corner diagonally to lower left; immediately turning back and describing a sinuous path, swept out all but upper left and lower right-hand corners. They, too, were soon involved. Cleared, beginning at lower right and upper left corners. Two streams coming from below, left and right, joined and passed upwards across after-image, sweeping it out. They turned and apparently wound back and forth over after-image several times, causing a long disappearance. Lower left corner cleared first. Light stream swept across from left to right and almost blotted out image. It turned broadly upwards, then sharply downwards as a heavy stream, blotting out image completely. Cleared, beginning at upper left corner. General agitation over after-image (convection-current effect). Colors of background and after-image mingled in the general swirling. After-image disappeared. Cleared. Stream started at bottom, bent towards right, turned on itself towards left, again upwards and towards right, and then downwards in broad S-shaped curve. After-image was blotted out. Faintly reappeared. Almost immediately was involved in a general swirling and vanished.

The next two observations serve, further, to demonstrate that when a stream sweeps across an after-image area, causing the after-image to disappear, it carries with it the visual quality, color and brightness, of the area from which it proceeds.

Stimulus: a strip of Milton Bradley standard yellow paper, 42 by 4 cm. on a sheet of Milton-Bradley standard blue paper, 52 by 59 cm.; giving as after-image on the field of the closed lids, a reddish blue strip on a reddish yellow background. Time of stimulation 30 sec. Distance of *O* 1 meter.

First the yellow background could be seen streaming gently over the after-image, gradually dimming it. Swirl of complicated curves blotted out whole after-image. Cleared slowly, and after-image could be seen here and there at the less dense places. Gradually cleared all over. Circular swirl cut out centre and about two-thirds of upper half. Cleared. Another swirl cut out small area at centre and moved diagonally upwards and towards right. Centre cleared. Streams, sweeping from right to left, joined at bottom of after-image, and traversed its entire length, returning upon themselves on curves having the shape of an ellipse. After-image cleared beginning at bottom. Lower part of after-image cut off by stream sweeping across to right, which turned and went obliquely towards left and upwards, cutting out centre. Cleared at bottom first. General swirling. At some places after-image was carried out into background, and background carried in; so that after-image presented irregular outline. Soon swirling became more violent and after-image and background intermingled. After-image became indistinguishable. Did not reappear. (In every disappearance the stream could be seen to carry the yellow of the background over the strip. This was especially

noticeable when the disappearance was progressive, from part to part. When, *e. g.*, a swirl, expanding, involved successively more and more of the image, the front of swirling yellow could be seen to encroach upon the blue at each revolution.)

Stimulus: a strip of Milton-Bradley standard yellow paper, 42 by 4 cm. on a sheet of Milton-Bradley standard blue paper, 52 by 59 cm.; giving as after-image on a sheet of engine-gray cardboard a strip of blue on a background of yellow. Time of stimulation 30 sec. Distance of *O* 1 meter.

Dimmed all over. Went out at centre, then at top and bottom. Reappeared. Bottom swept out; then whole image. Reappeared. Section in middle of upper half went out, followed almost immediately by section in middle of lower half. Both reappeared. Whole after-image blotted out. Reappeared, first at bottom. Top and bottom went out, followed by centre. Centre reappeared first. Long, slender, crescent-shaped section disappeared from right hand upper, then from left hand lower portion. Reappeared faintly, beginning with right hand upper corner; then whole image disappeared. Reappeared. Lower part disappeared. Reappeared momentarily; then whole image vanished. Reappeared faintly, and vanished. (At each disappearance, the after-image area occupied by the blue strip took on the yellow of the surrounding background, instead of preserving the gray of the cardboard. In many cases it could be seen to do this progressively; *i. e.*, the yellow would begin at a corner, an edge, etc., and spread in the direction in which the disappearance of the strip was taking place. The phenomenon was very clear, *e. g.*, when a corner, bottom, or what not went out, and the disappearance spread, finally involving the whole image. This type of disappearance, when observed on the closed lids, generally showed a swirling stream which spread centrifugally until the whole after-image area was swept over.)

4. The effect of streaming on the flight of colors is threefold. First, a gentle streaming may merely dim the color. Secondly, more intensive streaming advances the color changes one or more stages. When the change is advanced only one stage, the image sometimes does, and sometimes does not return to the preceding stage, when the stream has passed over. When the change is advanced two or more stages, the image apparently always returns to the initial stage, or to the initial stage but one, when the stream has cleared away. Thirdly, when the streams are strong and heavy, the image is blotted out completely, returning to the initial stage when the stream has passed on either abruptly, or quickly through the series of color changes,—most frequently in their inverse order, but sometimes in irregular order. These effects cannot be due to a shadow cast by the stream upon the retina; for shadows, like any reduction of the illumination of the retina, push the color change in the inverse direction. Hence we have here additional evidence that the locus of the physiological condition of streaming is not anterior to the retina.

The following is a description of the effect of streaming on the flight of colors.[1] An account of the phenomenon as it

[1] All the phenomena described in connection with streaming are

appears under still better conditions has been given above (after-image from the sun's disc).

The stimulus was afforded by a triangular opening, 1 by 2 ft., in a curtain near the ceiling of a closely curtained room. *O* was seated about 10 ft. from this opening, and looked up through it directly at the brightly illuminated sky. The sash of the window was lowered. In line with the centre of the opening was a patch of bright, fleecy clouds. Thus the stimulus consisted of a brilliant blue triangle with a bright white patch at its centre. When stared at for a long time, *e. g.*, for 5 min., the triangle underwent the following qualitative changes. The white patch at its centre became gradually dimmer. Finally, it became completely overcast with the surrounding blue. This was concomitant with intensive streaming of the swirling type. It cleared somewhat; then the whole triangle changed to a deep, saturated pink. After remaining in this stage for a short time, it changed again to blue, and finally once more to pink. Here the observation ceased. When the after-image was to be traced, *O* fixated the centre of the opening for about 20 sec., and then covered the closed eyes with a black cloth. The observation was thus made in a well-darkened field of vision. The report is as follows.

After-image developed as light faintly reddish blue. Fluctuated several times between this and yellowish green. (Thus far, as it happened, the streaming was not intensive.) Finally settled into yellowish green. Heavy streams frequently swept across, carrying it completely out. On reappearing, it came directly back to yellowish green once. The remaining times it reappeared first as deep red, then quickly changed into yellowish green. The yellowish green area grew smaller as fluctuation went on, leaving a growing border of deep red. Next fluctuation began from yellowish green to deep red, as a result of less intensive streaming. The yellowish green area was swept off, as if it were an upper layer, leaving the purplish red underneath and further back. One could see the yellowish green streaming raggedly beyond the after-image. This was very plain at times. Once a narrow stream was observed to cut a channel through the yellowish green near the toe of triangle, exposing the deep red apparently beneath. Disappearances also took place at this stage as result of heavy streaming. After-image finally settled down into deep red. This layer seemed to be noticeably farther back in the field of vision than the other color layers. Disappearances were quite frequent, and were plainly the result of streaming. This stage lasted relatively a long time. Next faint stages respectively of dark blue and dull dark yellow were noticeable. Fluctuations were frequent and disappearances long. There was the usual connection between fluctuation and streaming.

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noticeably plainer when the observation is made in the higher altitudes. Whether this result is due solely to the condition of illumination there found, which facilitates observation (especially when made in daylight on the field of the closed lids), and conceivably induces a more or less special retinal state, or whether indirect physiological influences are at work, the writer has no means of deciding.

The following is a variation of the streaming phenomenon, not observed in connection with after-images. It is given as possibly throwing some light on the physiological condition of streaming from a slightly different angle. The observation was made out of doors in Colorado, early in October, near the middle of a cloudless day. The light stimulation was very intensive.

Sometimes when the eyes, having been exposed to the bright diffuse light, were closed, and the field of vision had settled, one saw scattered over it here and there, and fairly close together, islands or patches slightly darker than the background, presenting a porous appearance, due to a peculiar mottling of lighter and darker gray. These patches were not after-images. They were, however, readily seen to be carried along and broken up by the streams, the parts taking the velocity of the stream current. Streams could be seen to cut channels through groups of the patches. The patches themselves seem to be conditioned by some mobile material, which shares in the general streaming.

Another phenomenon, which seems to indicate that there is even a mass mobility of the material which conditions visual sensation, is described as follows. The observation was made under the same conditions as the last.

When one has two or more after-images of the sun's disc close together, they will often be seen soon to merge into one. Sometimes a channel cuts across from the one to the other, and the two gradually draw together into a more or less circular form. Again, the one will be seen to move bodily towards the other, finally uniting with it.

5. That there is a dependence of streaming upon eye-movement cannot be doubted. This dependence is shown in two ways. First, when an eye-movement is noticeable, or is made voluntarily, a heavier stream is started in the apparent tangle of swirling in the direction of the eye-movement. Secondly, whenever involuntary eye-movement is increased, as by previous long fixation, by a faulty centering of the after-image upon the retina, etc., greater commotion is noticeable over the streaming area. That there is a movement of this material, independent of the effect of eye-movement, is also probable; but the heavy streams that intermittently blot out the after-image are doubtless determined by eye-movement.[1]

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[1]What the nature of the streaming material is we shall not attempt to decide, further than to point out that the results show it to be visually active. Metabolism requires that there be a diffusion of lymph over the retina. We might, then, identify the streaming material with this metabolic substance, making it the vehicle of both catabolic and anabolic processes. The anabolic material is conceivably in part disintegrated visual substance which retains for a time its power to condition visual sensation, as is shown by the streams bearing with them the visual quality of the region from which they come. Thus by weakening the after-image through hastening metabolic change, and by setting up strongly the sensation of the region from which the

c. When once we have established the connection between fluctuation and eye-movement on the one hand, and eye-movement and streaming on the other, explanation goes comparatively smoothly. The results obtained by varying the steadiness of fixation and by increasing the time of stimulation present no especial problem. There is in these cases merely an increase or decrease of eye-movement, and a corresponding increase or decrease in the streaming activity, with a resultant increase or decrease in fluctuation. With the remaining methods, however, the situation is different. They will be considered in turn.

(1) We have found that fluctuation occurs only within a limited region of after-image areas. Probably the most difficult problem that fluctuation sets to theory is this effect of variation of area. Before it, the oscillatory theory seems to break down absolutely.

Considered with regard to area, after-images naturally fall into four classes: small images which fluctuate little or not at all (for our observers, images with an area of 1.5 by 1.5 cm. and less); larger images which fluctuate over their whole area; still larger images which fluctuate in parts; and quite large images which do not fluctuate at all. Now this grouping is just what we might expect from the nature of the streaming phenomenon. It derives directly from the following facts: that streaming does not cause disappearance unless the stream comes from a part of the retina undergoing different stimulation; that the streams have a more or less definite form, *i. e.*, that they sweep across this or that part of the after-image, preserving pretty clearly defined borders; that vigorous streaming apparently occurs only over a somewhat limited region about the point of regard; and that the centre of the field of vision is always in a state of more or less violent swirling. Here the streams are narrow and swift-moving;[1] as we pass towards

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streams come, heavy streaming may temporarily obscure the after-image. It is, however, useless to work out in detail what, with our present knowledge of visual processes, can at best be but a mere conjecture. We desire to lay stress upon nothing except the observed facts.

[1] The direction of streaming is, as we have seen, determined or modified by eye-movement. The lines of direction described by all the points on the moving retina, for the various directions in which the eye moves, crowd together in its central portion; hence all the streams, since their directions are determined by the moving retina, converge towards its centre. This accounts for the narrowing of the streams, and the consequent more rapid motion of the streaming material. More or less continuous commotion at the centre must also result from these conditions; and the twisted, swirling, tangled patterns are produced by the many-times compounded motions. The centre of the retina is thus least liable to adaptation and after-image

the periphery, the swirling becomes more diffuse, and the streams are broader, and more widely separated both in space and time.

For convenience of discussion, therefore, the retinal field may be divided into four zones, each one of which usually, but not always, contains different stages of the same stream. The streams form near the periphery of the retina, and tend to move towards its centre. In the first or central zone, streaming is practically continuous. Here the streams are narrow, swift, and often crowded together. The second zone is made up in part of cross-sections of the streams found in the first, and in part of streams whose directions have been changed before they reached the first zone. Here the streams are broader and less swift and vigorous. The streaming at any given point is discontinuous; a given segment of the zone is streamed over at irregular intervals. In the third zone are found, in general, the source and the upper courses of the streams passing across the first and second zones. The streaming here is still more discontinuous, and the streams are still broader and more sluggish. The fourth zone lies beyond the area of observable streaming.

The infrequency or entire absence of fluctuation of the small images of the first group is explained by the fact that they lie wholly within the first zone, the region of most active commotion. Hence, when they have once reached the dimness at which disappearance begins, there is not sufficient lull in the streaming for reappearance to occur. The records show less eye-movement for the images of the first than for those of the second group. Here we come upon an exception to the general law of the effect of eye-movement upon fluctuation; for this reduction of eye-movement favors rather than decreases the fluctuation of these small images. It is, however, readily intelligible that a more continuous eye-movement, by causing more continuous streaming, would give even less opportunity for reappearance.

The images of the second group extend beyond the limits of the central zone; and the continuous streaming of this region does not cause them to disappear, since to do so the streams must come from a region of different stimulation. They lie, however, within the second zone, where the streaming is still vigorous though not continuous. A broad heavy stream sweeps in from the outside, and may either blot out the whole image at once (this depends upon the relative sizes of stream

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effects. This conclusion tallies with well-known facts of vision. The centre of the retina is the region of clearest vision; adaptation there takes place less quickly, and the correlated after-images develop more slowly.

and image), or may at first efface only a part. Then, as the stream compounds with other streams, the whole image will become involved. When the commotion subsides, the image reappears, remaining until blotted out by another stream or stream-system. Since we are now in a region of only occasional streaming, increase of eye-movement must increase the frequency of fluctuation, by increasing the number of streams that sweep across the image. There is, however, sufficient intermission in the streaming for reappearance to take place. Continuous voluntary eye-movement would probably produce continuous streaming over this region; but, under the conditions of ordinary fixation, we have a fluctuation which is proportional to the frequency and range of eye-movement.

The images of the third group are still included in the region of streaming. They lie within the borders of the third zone, but are too large to have their whole area involved at one time by a single stream or stream-system. So we have the phenomenon of fluctuation in parts. As in the previous case, increase of eye-movement increases streaming, and accordingly increases frequency of fluctuation.

The images of the fourth group cover the whole area of effective streaming. Their borders lie in the fourth zone; and consequently fluctuation does not occur. The streams that twist about over the surfaces of these images do not come from a region of different stimulation, consequently do not blot them out.[1]

(2) We found that the form of the stimulus affects the frequency of fluctuation and the duration of the after-image. The stimuli used were strips and squares of equivalent areas. We now have to explain, first, the shape of the curve of frequency for the strip-images. An increased length of strip, while it produces practically the same effect on eye-movement as increased area of square, does not give the same shape to the curve. With the squares the curve, after reaching its maximal height, bends down rather sharply to the abscissæ;

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[1] The explanation in this and the following sections may seem somewhat complicated; but the facts are themselves complicated. The results of observation are recorded as they were obtained, in no wise modified to suit the needs of theory. The phenomena of streaming and the phenomena of fluctuation were investigated independently and at different times. The details of streaming, its patterns, zones, etc., were worked out, and in part verified, a full year before the results on fluctuation given in the foregoing tables were obtained. After those results had been obtained, however, for variations in size, form, arrangement, etc., of stimulus, the present investigations were begun, with projection of the images on the field of the closed lids, in order to determine the relation of the various types of fluctuation to the various types of streaming. Thus our theory is, in reality, a description of what actually takes place in observation.

with the strips, it dips down very little. The explanation is that the squares, as they grow larger, come to include the whole of the noticeable streaming area, while the strips do not. The strips can, accordingly, always be swept across by streams coming from a region of different stimulation. They can be blotted out, while the squares cannot. The shape of the curve for the strips is very like that for the squares until the maximal height is reached; up to this point streaming affects both strips and squares alike.

We have to explain, secondly, the fluctuation of strips and the partial absence of fluctuation of squares of equivalent area. The explanation lies in the difference of the retinal zones. The squares fall within the first and the innermost part of the second zone. The strips, in proportion as they are included within the first, second and third zones, show the phenomena of fluctuation characteristic of these regions.

(3) We found that the arrangement of the stimulus, with reference to the direction of greatest eye-movement, affects the frequency of fluctuation and the duration of the after-image. Narrow strips of varying length undergo more frequent fluctuations and have a shorter duration when the direction of greatest range and frequency of eye-movement is across the strip, than when the inverse arrangement obtains. The reason is clear: the streams must be more effective to produce disappearance when they sweep across the narrow after-image, than when they traverse its length. Suppose, *e. g.*, that a narrow strip is placed with its length first in the vertical and then in the horizontal plane. Let the eye-movement, in both cases, take place in the horizontal plane. The vertical strip can be more effectively swept by streams coming from a region of different stimulation than can the horizontal strip. Accordingly we find greater frequency of fluctuation and a shorter duration of the image in the former case than in the latter. Conversely, when the movement is in the vertical plane, and the strip is arranged first vertically and then horizontally, the opposite effect should be produced. The tables show that this is the case.

In the experiments on natural fluctuations, the greater range and frequency of eye-movement, for all observers, were in the horizontal plane. Hence greater frequency of fluctuation and shorter duration should have been observed when the strip was arranged with its length in the vertical plane. The tables show that this expectation was realized.[1]

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[1] The character of the disappearance is somewhat different, according as it is due to voluntary eye-movement or to natural fluctuation. In the former event it is more abrupt, and more nearly covers the whole length of the image. In natural fluctuation, the image usually

(4) Having thus ascertained the part played by streaming in the determination of the duration and fluctuation of the after-image, we can understand how it is that results obtained when the fluctuations were produced by involuntary eye-movement, varying in amount from method to method, could be duplicated by results obtained when the fluctuations were produced by voluntary eye-movement, constant from method to method. There are two possible reasons. First, there was present in both cases a variable amount of involuntary eye-movement; and secondly there was in both cases the same distribution of the zones of streaming.

There can be no doubt that voluntary eye-movement, while it lessened, did not entirely prevent involuntary movement. In the variation of this latter, from method to method, we might find a basis for the variation in results obtained, and therefore an explanation of the duplication. On the other hand, there is strong evidence that the concomitant involuntary eye-movement was not the direct cause of fluctuation. The disappearances always followed directly upon the voluntary movements, which must, therefore, be regarded as the immediate cause of fluctuation. The involuntary movements could have functioned only indirectly, by way of weakening the after-image, under certain experimental conditions, and thus rendering it more liable to obliteration by the voluntary movements. Obviously, then, the distribution of the zones of streaming is the more important factor.

It is not difficult to see how these two factors co-operated to produce our results. If there were no variation of involuntary eye-movement, from method to method, strict duplication should result when the fluctuations are produced by voluntary eye-movement. If it were not for the identical distribution of the zones of streaming, duplication could not result at all. A consideration of the two factors together enables us to explain the results obtained.

(5) The peculiarities of fluctuation in indirect vision are readily explained as a result of the distribution of the zones of

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goes out in successive parts, quickly, until it has disappeared. The difference reflects the nature of the eye-movement. The voluntary movement is a single sweep, out and back, of considerable strength and range. A broad current of the streaming material is thus carried across the image in the direction of the eye-movement, and blots it out at once. The involuntary movements occurring in the case of natural fluctuation are irregular in direction, range and frequency, and usually come in groups. They therefore start a number of streams in different directions, and usually in quick succession. One stream is often seen to sweep across this part, another across that; until finally the whole image becomes involved before any part has had time to clear.

streaming. When a small after-image is observed, first in the central part of the field, and then successively farther and farther out from the centre, there is first an increase in fluctuation, then a decrease, and finally an entire cessation. Now we have seen that an image in the central zone of streaming, once it has disappeared, is kept from reappearing by the continuous commotion there present. As it passes from the central zone outward, into the region of occasional streaming, fluctuation must increase up to a certain point (probably the limits of the second zone), and thereafter decrease, ceasing entirely when the image passes beyond the range of noticeable streaming.

(6) Fechner,[1] Helmholtz,[2] and others maintain that blinking and movement of the head, as well as movement of the eyes, cause the after-image to disappear. Both of these movements, however, result in eye-movement, and hence may be supposed to be only indirectly causes of disappearance.

With regard to blinking, O. Weiss says:[3] "Beim Lidschluss zeigt sich eine Bewegung des Bulbus erst nach oben innen, dann nach oben aussen." This is called Bell's phenomenon.[4] The movement can easily be felt when one presses the finger with moderate firmness on the lids, above and to the temporal side of each bulb, and blinks vigorously. Von Michel[5] thinks that this movement-complex is controlled by the cortex, while Nagel[6] believes it to be a reflex, due to the pressure of the edges of the lids upon the cornea. However this may be, there is distinct eye-movement, in at least two directions, with every closing and opening of the lids; that is to say, there is ample ground for considering eye-movement to be the more immediate cause of the disappearance of the after-image.

Again, even if the eye were stationary in its socket, movement of the head would affect the streaming phenomenon very much as movement of the eyes does. The streaming material would traverse the retina in the opposite direction to that of the movement.[7] But the eye is not thus stationary; movement of the head results either in a movement of the eye in the opposite direction, or in this together with a readjustment of the eye in accordance with the changed position of the head. And there is, further, a rotation of the eye about its horizontal axis, which, according to Donders, opposes the rotation of the head

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[1] Ann. d. Phys. u. Chem., L, 1840, 221.
[2] Phys. Optik, 510.
[3] Nagel's Handbuch d. Physiol. des Menschen, III, 1905, 471.
[4] Philos. Transact. of the Royal Soc., 1823, 166, 289.
[5] Beitr. z. Physiol., Festschr. f. Fick, 1899, 159.
[6] Archiv f. Augenheilk., XLIII, 199.
[7] This would be in the same direction as the movement of the field of vision, the converse of what happens with eye-movement. The effect on the after-image, however, would be essentially the same.

and is of equal amount in both eyes. In the case of a sudden inclination of the head, Mulder[1] found a momentary torsion of 20°. His conclusions as regards permanent torsion bear out those of Skrebitzky.[2] Nagel[3] found that movements of torsion occur if the head or the head and body together are passively moved.

In fine, then, the effect upon the after-image of blinking and of movements of the head presents no especial problem to theory; in both cases definite and measureable eye-movements take place. Eye-movement, as determining or modifying the streaming phenomenon, explains fluctuation under these conditions as readily as it explains the fluctuations which occur under the conditions of normal fixation.

III. Conclusions and Restatement of Thesis

The conclusions to be drawn from the foregoing experiments, with regard to the fluctuation and duration of the negative after-image, are as follows. (1) The fluctuation of the negative after-image represents a real intermission of sensation. It is not an artifact, due to observation under the conditions of light adaptation, for it occurs as readily in a darkened as in a light field of vision. (2) Fluctuation is not grounded in the nature of the after-image process. It is caused chiefly by involuntary eye-movement. (3) Eye-movement causes the fluctuation and decreases the duration of the negative after-image by conditioning or modifying the streaming over the retina of some material capable of affecting the visual processes.

Enlarged and restated in the light of these conclusions our thesis is this. (1) The intermittence of minimal visual sensation is a phenomenon of adaptation. (2) Adaptation is rendered intermittent chiefly through the influence of eye-movement. (3) Eye-movement interferes with adaptation in three ways. (*a*) It decreases the total time of stimulation. The more eye-movement there is, the less intensive will be the impression made upon the retina. (*b*) It affords time for the after-image to die away, or (in terms of adaptation) it gives opportunity for restoration, proportional to the length of time during which the stimulated area is relieved. And (*c*) more immediately, it determines or influences the washing or streaming over the retina of some material capable of directly affecting the visual processes. Further evidence for this thesis will be adduced in later papers.

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[1] Archiv f. Opthalmol., XXI, 1, 1875, 68.
[2] Archiv f. Opthalmol., XVII, 1, 1871, 107.
[3] Archiv f. Opthalmol., XVII, 1, 1871, 237.